

IRE Transactions



ON VEHICULAR COMMUNICATIONS

Volume VC-10

APRIL, 1961

PERIODICAL
Number 1

ELEVENTH ANNUAL PGVC CONFERENCE PHILADELPHIA, PA., DECEMBER 1-2, 1960

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PROFESSIONAL GROUP ON VEHICULAR COMMUNICATIONS

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PRINTED IN THE U.S.A.

PERSONAL RADIO SYSTEMS AND APPLICATIONS

John F. Mitchell
Motorola, Inc.
Chicago, Illinois

Summary

This paper is a discussion of the system aspects of radio systems designed to use the new types of Personal Radio Equipments which have been, and are being, introduced to the market in increasing numbers and types. Several actual applications are discussed. These examples cover the two basic types of equipment now in use, which are two-way non-selective call units, and one-way selective calling paging units.

The basic capabilities of the personal equipment are examined insofar as they pertain to Personal Radio System Design. The limitation and advantage of this equipment as well as the new uses and applications of this equipment are treated.

Introduction

The use of personal radio equipment has expanded rapidly since its introduction only two years ago. The user of this type of equipment now has a wide variety of units from which to choose to do his communications job. Personal radio equipment has new dimensions of size and weight and thus it has developed new applications of two-way radio.

One-Way Systems

There are two general types of personal radio systems, one-way or paging systems, and two-way systems. In the paging system, the user wears a small receiver which can receive an alerting call and a voice message. Fig. 1 shows the Pocket Pager. This unit responds to a coded alert call by making a loud tone. The user then can listen to a voice message by depressing the push-to-listen switch on the unit. The alerting tone has seven-tenths of a watt of audio output and the audio power output on voice is one-half watt into a one and three-quarter inch speaker. The weight of the unit is less than fourteen and one-half ounces and it has a battery life of over three weeks. The alerting tone sensitivity is less than .5 uv in the 150 Mc band and less than .25 uv in the 50 Mc band. The selective calling capacity is one of seventy-five hundred individual calls on one RF channel.

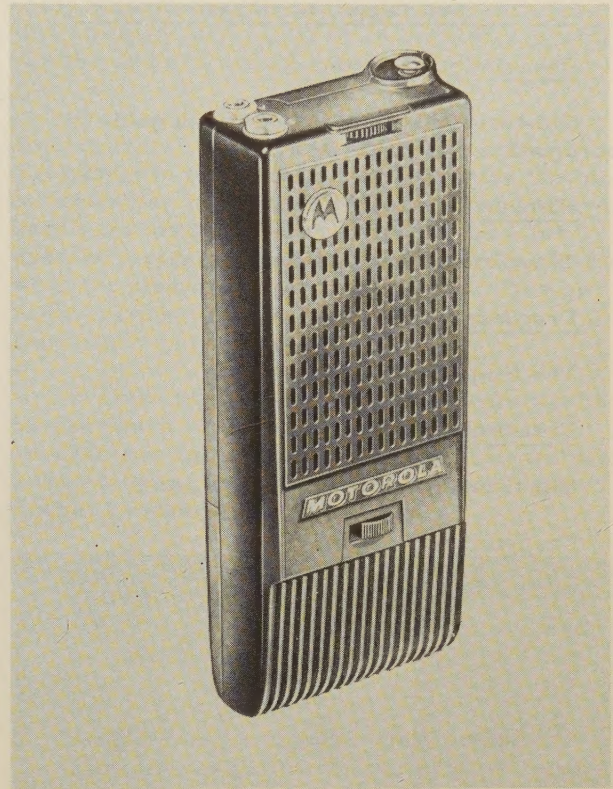


Fig. 1 - Motorola "handie-talkie" pocket pager.

This type of product is making new uses of the valuable radio spectrum while using very little "air-time". Pocket pagers can be added compatibly to any of the low or high band, wide or narrow vehicular systems. In fact, the selective calling scheme is compatible with standard mobile selective calling and the base station's encoder equipment is the same for mobile selective calling and for small paging systems of up to 360 users. In larger systems of up to 7500 calls the base RF equipment is again the identical equipment used for vehicular two-way communications, but the encoding equipment is a separate device controlled remotely by push-button fast-dial type control points.

Let's look at an interesting application of this type of equipment in a typical system. The University of Michigan has a Pocket Paging System at the Ann Arbor Campus for use by their maintenance crews.

Specifications on the University of Michigan
Pocket Paging Radio System
Ann Arbor, Michigan

1. Description of System

This paging system is used principally to coordinate maintenance activity.

2. Number of Units in System:

There are 45 pocket pagers in use.

3. Frequency:

The frequency is 35.94 Mc.

4. Transmitter Power Output:

The transmitter power is 100 watts.

5. Transmitter Location:

The transmitter is located in the Burton Memorial tower.

6. Control Point Location:

The control point is located in the plant department building approximately 2 miles from the transmitter location, connected by two wire line.

7. Antenna Location:

The antenna is located on the roof of Burton Memorial tower.

8. Antenna Height:

The antenna is 250 feet above ground.

9. Antenna Type

The antenna type is an Andrews Unipole.

10. Coverage Desired:

The desired coverage was 6 to 7 miles.

11. Coverage Achieved:

The coverage achieved was 15 to 20 miles outside the buildings. Messages are received

very well at 7 miles inside of the 135 buildings, and also in the elevators of some of the buildings across the 1,356 acre campus.

With 135 buildings on the campus, it is apparent that there is a communications problem in the direction of maintenance personnel across the campus. The ability to add one-way paging to their two-way system has greatly increased the utilization of the campus radio system for use by the maintenance crews.

Two-Way Systems

The second general application of personal radio is the two-way systems. This type of system is the same as our conventional vehicular system with the user wearing both a receiver and a transmitter. The Pocket Receiver is similar to the Pocket Pager except it has a standard noise-operated squelch circuit instead of a selective calling circuit. It, therefore, can listen to all messages on the channel. It has many interesting characteristics despite its small size, such as .5 watts of audio output, 1 uv sensitivity in the 150 Mc band and .5 uv sensitivity in the 50 Mc band. The drain is less than 5.5 ma from 10 volts and the battery life is 125 hours on a 10% listen and 90% stand-by duty cycle. It can be powered with either mercury or nickel cadmium batteries. The transmitter now in use in this type system is a tube unit.

The Baker Properties Company in Minneapolis, Minnesota has a typical radio system using Pocket Receivers and Pocket Transmitters. The Company owns buildings in the downtown area of Minneapolis, which they rent and maintain. Communications with their maintenance people, especially in an emergency, is their basic reason for using radio. With the pocket equipment in this system, the maintenance people can be reached at all times, rather than only when they are at a known phone number or in a radio-equipped car.

Specifications on the Baker Properties
Pocket Equipment Radio System

1. Description of System:

This system is used by the maintenance department of a firm that owns and operates 9 buildings located in three groups in downtown Minneapolis.

2. Number of Units in System:

There are 6 pocket receivers and 2 pocket transmitters in the system.

3. Frequency:

The frequency is 151.895 Mc.

4. Transmitter Power Output:

The transmitter power output is 60 watts.

5. Transmitter Location:

The transmitter location is the elevator machine room on the 12th floor of the Baker building.

6. Control Point Location:

The control point location is in the switch-board room on the 5th floor of the Baker building.

7. Antenna Location:

The antenna location is on the roof of the 12th floor of the Baker building.

8. Antenna Height

The antenna height is 5 feet above the roof or approximately 175 feet above ground.

9. Antenna Type

The antenna type is a Motorola ISO-PLANE antenna.

10. Coverage Desired

The coverage desired was 5 to 6 miles.

11. Coverage Achieved:

The coverage achieved is six miles to the pocket receivers.

The air conditioning and elevator maintenance for all buildings is handled by two three-man central crews. With this type of arrangement all individuals -- the supervisors and the maintenance men -- must spend a great deal of time walking between the various buildings. This high level of mobility made communications very difficult prior to the installation of the pocket radio system. Since the repair men must be contacted before they can fix a breakdown, much time was spent trying to track down key personnel during the day. The radio system has eliminated this. The result is, of course, a higher degree of operating efficiency and better tenant service.

The elevator men and air conditioning men each wear a small Pocket Receiver, as do the

three building group superintendents. The system also includes two Pocket Transmitters. These units are taken from the office by the repair men whenever they know they will be working on a certain project where two-way communications is needed. The chief elevator mechanic reports the transmitter is used whenever he and his elevator technician are working together on a job that requires one man to be in the elevator tower and the other in the cage itself.

The use of the communications system in emergencies is the prime reason for Pocket Equipment in this system. Any elevator trouble, for example, is an emergency situation. There have been instances when a man is just a few hundred feet from a building with a faulty elevator when the elevator girl puts in a call. Through radio communications, he is on the spot in seconds.

In these two-way systems, a transmitter is needed which is easy on battery cost and is smaller and lighter. Motorola has designed such a transmitter. It is called the "Handie-Talkie" Pocket Transmitter.

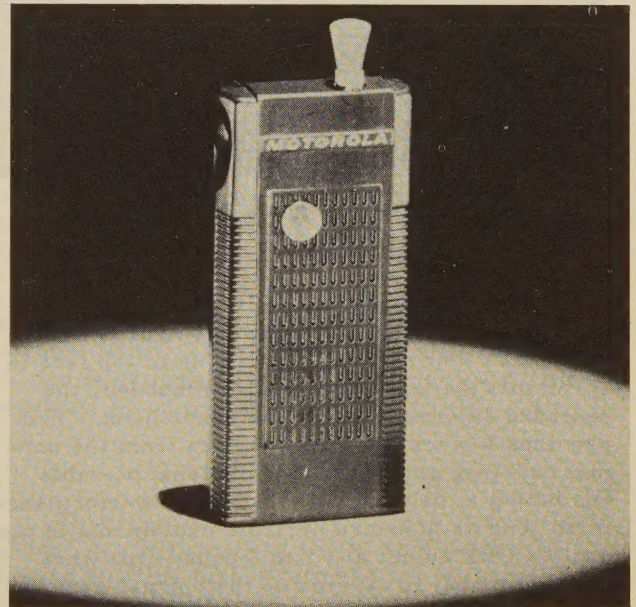


Fig. 2 - Motorola "handie-talkie" pocket transmitter.

This is an all transistorized unit, and it has one-half watt of power output designed around the new Motorola 2N1692 VHF power transistor. It has the expected features of a unit designed to meet the rigorous requirement of personal radio service. It has a dynamic microphone, adjustable "instantaneous deviation control", crystal-controlled oscillator with $\pm .0025$ stability, and

a transistor phase modulator. Fig. 2 is a view of the unit which is designed in a high-impact plastic case. Note the antenna collapses into the top of the unit. The push-to-talk switch is on the left and the microphone is behind the front grill. To operate the unit, the antenna is extended and the unit is held up to the face and used as a microphone. Fig. 3 shows a police officer operating the unit.



Fig. 3 - Pocket transmitter in use.

Let's look at the system's aspects of this unit. As I have said, the power output is one-half watt. Since the unit is held up to the face to speak into the self-contained microphone, the extended antenna is above the users head. This provides a much improved pattern from the normal carrying position of conventional portable equipment at belt height. The range performance is as good as standard portable equipments of the one-watt RF output and 7 to 8 pound type when that equipment is carried on the normal carrying strap, and the radiation pattern of this pocket transmitter is more uniform.

Systems using a 150 ft. receiving antenna with 4.3 gain can expect to have solid coverage of over 7 miles with this unit; and very weak spotty coverage has been achieved in a suburban area of 14 miles. The range to a pocket receiver with a dipole antenna, such as a hat antenna or to a standard portable radiophone, is about 1.5 miles in a suburban area.

Another interesting aspect is the size of the Pocket transmitter, which is 5 1/2" x 2 1/2" x 1 1/8". In Fig. 4 it is compared to the tube unit. In Fig. 5 it can be seen that it is a mate to the Pocket Receiver. The weight of the transmitter is 14.5 ounces. The tube unit was 45 ounces. The battery voltage is 14 volts using either four mercury type #133 or TR133R batteries, or nickel cadmium rechargeable batteries which are interchangeable. The battery life is 80 hours with mercury batteries, or 8 hours per re-charge with the nickel cadmium batteries. The drain is only 1.8 watts for a total efficiency of 27.5%. This compares to 7.4 watts or 10.8% on the tube units. This is an operating cost reduction of ten to one considering a 10% duty cycle. The battery cost of a tube unit, operated for a year on a 10% duty cycle, will pay for two transistor units and their batteries.

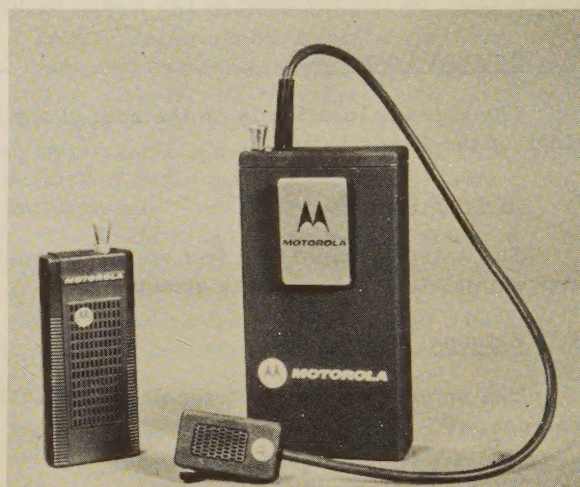


Fig. 4 - Pocket transmitters - tube and transistor units.

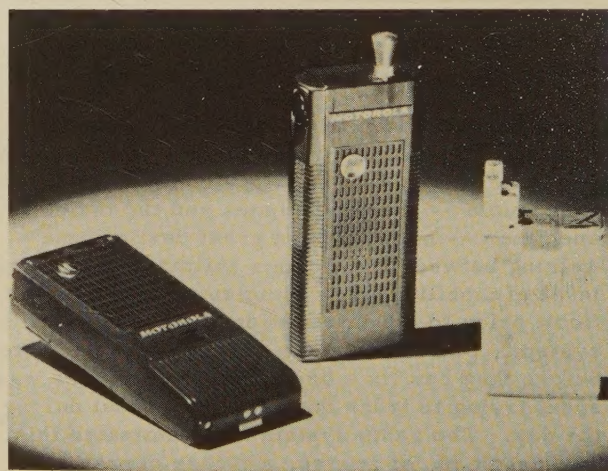


Fig. 5 - Pocket transmitter and pocket receiver.

Fig. 6 shows the method of battery replacement. The batteries are held in two tubes along side of the transmitter chassis and are removed by turning the battery plugs one-quarter turn.

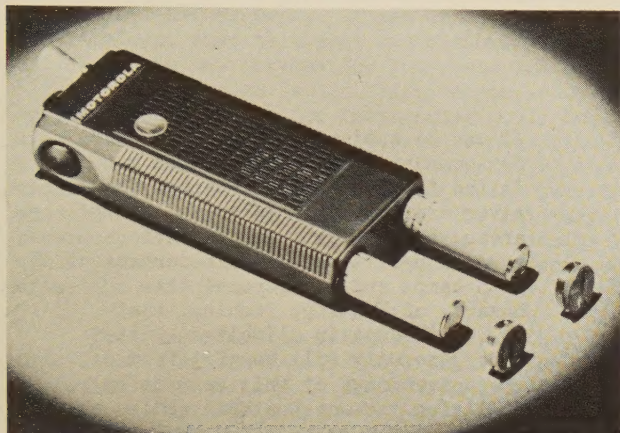


Fig. 6 - Battery access on pocket transmitter.

If the antenna is damaged, it can be unscrewed and another one screwed into its place. A fixed 18-inch whip antenna is also available that screws into the same fitting.

Fig. 7 shows the back plate removed which can be done by the removal of four screws for easy access by the serviceman. In this view, it can be seen that the transmitter is constructed on one single printed board with all connections exposed for metering at the marked metering points or for touch-up of the alignment. All connections are made on this one board so that actually every voltage in the radio can be measured with just the cover removed. However, when a part must be changed, the board can be lifted out and serviced from both sides, while still connected to the battery by its service cable. Fig. 8 shows the transmitter removed from the housing for service.

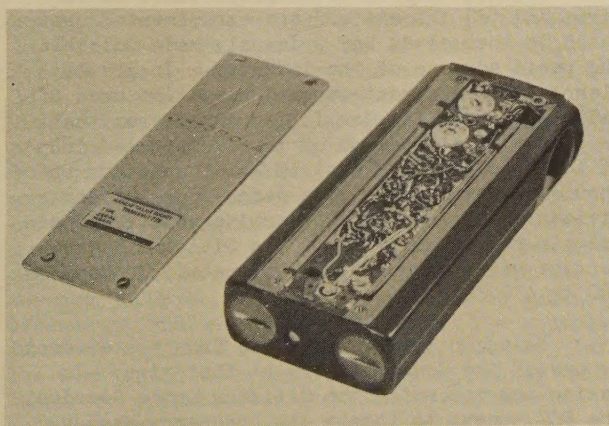


Fig. 7 - Pocket transmitter open for service.

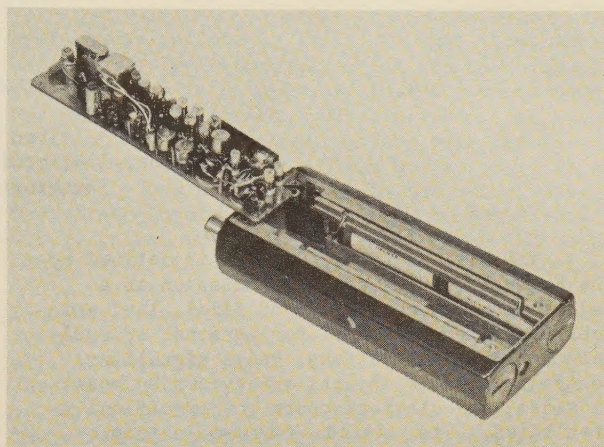


Fig. 8 - Pocket transmitter removed from housing for service.

The transmitter also has a group of accessories such as battery chargers, for the nickel cadmium batteries. By removing the quarter-turn battery plugs, a quick conversion of any unit can be made to a rechargeable nickel cadmium battery. The battery plug fits both mercury batteries and nickel cadmium batteries, but will not allow charging of a mercury battery if it is placed in a charger. When the unit with rechargeable batteries is placed in the charger, a red lamp lights showing the battery is charging. Chargers are available for charging the battery while in the unit by placing the complete unit in the charger, or to charge the battery separately.

The transmitter is provided with a carrying case. It fits this case snugly, as in a holster, to make sure the unit will not pop out. It also has a retaining strap as an added safety.

The unit in another version has an interchangeable back that can be used when it is desirable to use the transmitter without the case. A clip on the back permits fastening the unit in a pocket or on a belt.

Conclusions

This transmitter is the unit the systems engineer has been waiting for to have all the required building blocks to make his personal radio system complete. I believe it is apparent to all that personal radio systems are a new and interesting use of the radio spectrum. These systems must be properly designed to take advantage of the capabilities of this small size equipment; but they must also be designed within the limitations of the equipment -- which are primarily the reduced range resulting from the small receiver antennas and the low power output of the transmitters. However, properly designed systems can achieve a substantial step forward in the art of radio communications.

THE CITIZENS BAND BOOM

Ivan H. Loucks
Federal Communications Commission
Washington 25, D. C.

The Citizens Radio Service is defined by the Federal Communications Commission as a radiocommunication service of fixed, land and mobile stations intended for personal or business radio communications, radio signalling, control of remote objects or devices by means of radio, and other purposes not specifically prohibited. Its stated purpose is to provide for the use of radio facilities by any citizen of the United States for private short-distance radiocommunications, radio signalling, or the control of remote objects or devices by means of radio. Let us trace its beginning, its progress, and its present situation, -- and make some predictions on its possible future.

During the closing months of World War II, the FCC conducted a series of fact-finding inquiries and hearings which culminated in a Report of Proposed Allocations dated January 16, 1945, covering the frequency range from 25 megacycles to 30,000 megacycles, and bearing the designation Docket No. 6651. In that Report the Commission proposed an equitable peacetime allocation of the then useful radio spectrum above 25 Mc, to provide for the reasonable known or estimated needs of all segments of the American public whether local governments, industries, or private individuals. To meet that latter need - to make possible the fullest practicable development of private radiocommunications within the limits set by other demands for assignments in the spectrum - the Commission on its own motion proposed to allocate the band 460-470 megacycles to a new radio service, to be known as the Citizens Radio Service.

I quote portions of the Commission's own statements in this respect:

"The possible uses of this service are as broad as the imagination of the public and the ingenuity of the manufacturers can devise. . . . Department stores, dairies, laundries and other business organizations can use this service in communicating to and from their delivery vehicles. Similarly, it can be used in communicating to and from trucks, tractors, and other mobile units operating in and around large industrial plants and construction projects - many of which spread over a number of square miles.

It can be used on farms and ranches for communications to and from men in the fields; on board harbor and river craft; in mountains and swamp areas, etc. Sportsmen and explorers can use it to maintain contact with camps and to decrease the hazards of hunting, fishing, boating, and mountain climbing. Citizens generally will benefit from the convenience of this service by utilizing two-way portable radio equipment for short range private service between points where regular communication facilities are not available. . . ."

The Citizens Radio Service was not possible before World War II because sufficient frequencies in the higher portions of the radio spectrum had not been developed to meet the needs of other more-pressing services. That was the situation despite the fact that the usable radio spectrum was already a hundred times larger than in 1925, when for all practical purposes it ended around 3,000 kilocycles. By 1940, the ceiling of formal allocations was 300,000 kilocycles, but only the frequencies up to possibly 100 Mc were really in effective use. The field was limited, as today, by the large number of frequencies, or large amounts of spectrum space, reserved for U. S. Government use (including the military), and the Commission was able to provide frequencies for only four classes of use: - (a) Broadcasting, and this included the early days of F.M. radio; (b) Safety services, such as aviation, maritime, and police activities; (c) The common carrier radiotelephone and radiotelegraph services for hire; and (d) the amateur and experimental uses which in themselves had primarily made possible the rapid advance of the industry. In its 1945 planning for the post-war and peacetime uses of radio, however, the Commission considered that in proposing allocation of the frequencies from 25 to 30,000 Mc, at least 10 Mc of spectrum space should be reserved for the general use of any citizen or business not otherwise able to obtain private radio facilities. The Citizens Radio Service was thus born, and allocated the band 460 to 470 Mc.

To again indirectly quote from a statement by one of the Commissioners at that time: In making provision for the Citizens Radio Service, the FCC sought to locate its frequency band as far down as possible in the spectrum to make it more readily available for use. However, owing

to such needs as those of F.M. Broadcast, television, police communications, aviation, and government agencies, the lowest spot that it could assign for the personal use of citizens was the 460-470 Mc band. It was considered nevertheless, that this spot was admirably suited to the new service for two reasons. First, no long-range "skip" interference would be experienced, hence the frequencies would be available for multiple short-distance communications with reasonable geographic separation, and second, it was felt that because of their experience in making radio equipment for the military services, manufacturers would be able to design and construct sets for these frequencies soon after the end of the war.

The first developmental (called at that time Class 2 experimental) authorization for the operation of a station in the Citizens Radio Service was issued to Mr. John M. Mulligan, a radio engineer of Elmira, New York, on February 14, 1947. It was followed in June of that year by proposed technical standards for equipment to be used in the service, which were modified to some extent and adopted by the Commission in October, to become effective on December 1, 1947. These standards made provision for the type-approval of equipment to be used in either of two classes of stations to be operated in the Citizens Radio Service. The first appropriately called Class A, was to be subject to fairly strict technical standards, roughly equivalent to those imposed on other services using comparable frequencies, and was to be permitted up to 50 watts (input) power when operating on frequencies in the 460-462 or 468-470 Mc portions of the band, but only ten watts (input) elsewhere. The second, Class B station was limited to ten watts input power, but the technical standards were such that nearly any equipment could be used so long as all operation (including tolerance and the occupied bandwidth) was confined within plus or minus 0.4% of 465 Mc. (This was changed to 0.5% in 1950.)

The first certificate of type-approval under these standards for equipment to be used in the 460-470 Mc band in the Citizens Radio Service was issued by the Commission in March of 1948, to cover a hand-carried radiotelephone transceiver for Class B service, the prototype of which was submitted by the Citizens Radio Corporation of Cleveland, Ohio. This unit employed an amplitude modulated self-excited oscillator, using internal tuned lines for frequency control. It was found to meet the requirements for licensing at Class B stations in the service; however, it was not produced in quantity because of production difficulties. The apparent imminent availability of equipment, however, led the Commission to proceed with establishing rules to govern operation of stations in the service on a regular basis. The formal rule-making proceeding was finally concluded in March of 1949, and the licensing of Class A and Class B stations in the Citizens Radio Service on a regular

basis began on June 1, 1949. At that time, the majority of type-approvals which has been issued for equipment to be operated in the service were for Class A station equipment; however, the greatest number of authorizations were for developmental operation as Class B stations. This apparently was primarily due to the use of converted war-surplus equipment such as the BC-645 I.F.F. units, which were licensed on an individual basis rather than as a group meeting the requirements for type-approval. The actual number of licenses issued under the new rules, however, was quite small -- there were only 1401 stations, in all, licensed in the Citizens Radio Service on June 30, 1952. Of these, approximately one half or more were Class A authorizations indicating the use of commercial type equipment and undoubtedly commercial type usage rather than in satisfying a personal communication need. It may be noted that one of the principal commercial-type uses for Class A station facilities was at that time, and possibly still remains, the provision of private point-to-point communication circuits where common carrier facilities were not available or were not economically feasible. The Commission had already foreseen the possibility of the Citizens Radio Service being pre-empted by all kinds of commercial type usage and had limited authorizations to those cases in which the applicant would be unable to satisfy his communication needs by the use of private facilities licensed in any other of the established services. This limitation remained in effect until just prior to the advent of the Class D stations, when it became no longer necessary. It remained, however, for type-approved Class B equipment to become more generally available, within a low-price range attractive to the individual, before the original intent of the Commission with respect to making radio communications available to every citizen began to be fulfilled. In the meantime, a new class of station was added which also had its effect on the service.

Early in 1949, the Academy of Model Aeronautics pointed out to the Commission the need of its members and other persons desiring to control model aircraft or other remote objects by radio, for a frequency or frequencies for that purpose and the (then) unsuitability of the 460-470 Mc frequencies. At the time, there did not seem to be any solution other than operation in the Amateur Radio Service, and the Academy was so advised. However, in 1951, the ISM band 26.96-27.28 Mc was subdivided and made available for other uses as well. The band 26.96-27.23 Mc was assigned to the Amateur Radio Service, and the frequency 27.255 was made available to a large variety of other services, including the Citizens Radio Service. In that service the frequency was made available to a new class of station, called Class C, which was established in February of 1952 and authorized to be used only for the radio control of remote objects or devices. In addition to the remote control of model aircraft, model boats, etc.,

Class C stations found early acceptance for such uses as the radio control of garage-door openers. Also, the rules were changed in 1956 so as to permit Class C stations to be used for the activation of devices used for attracting attention, such as pocket paging receivers in hospitals, factories, or department stores. This class of station can be largely credited with the growth of the Citizens Radio Service from a total of 1,401 outstanding licenses on July 1, 1952, to 3,829 on the same date in 1953, to 7,054 one year later, and to 12,334 on July 1, 1955. No detailed statistics are available, but based on a partial count, it is estimated that on July 1, 1955, there were approximately 1,500 Class A stations, another 1,500 Class B stations, and approximately 9,000 Class C stations. This picture changed shortly thereafter with the general commercial availability of type-approved Class B station equipment, resulting from a relaxation of the Commission's technical standards governing such equipment. Although that relaxation actually took place during 1953, the most popular equipment which was type-approved for radiotelephone operation under the revised standards became available to the public just prior to the Christmas holidays in 1955. The result of that was a rapid increase in the number of Class B station licenses, although Class C stations still remained in the majority. Another partial count of licenses, taken in May of 1957, indicated that of the 25,759 stations licensed in the Citizens Radio Service at that time, less than 10 percent (approximately 2,500) were Class A, slightly more than 25 percent (approximately 7,000) were Class B, and the remainder (approximately 16,500) were Class C. It may be noted here that garage-door openers and many other types of "gadget" controls are also prevalent in the Class B station category -- a considerably greater number of type-approvals have been issued by the Commission for Class B "control" transmitters than for Class B radiotelephone equipments. Since the only requirement for Class C transmitters is that they be crystal-controlled, there is no record of available information as to how many different types of equipment are in use under that category; i.e., whether for garage door or model control, or for paging systems, etc.

In 1957, as the aftermath of detailed and lengthy proceeding which set up new "narrow-band" technical standards to govern most of the Commission's land mobile service, a partial reallocation was undertaken to dispose of the "split channels" in those services and to make other adjustments in spectrum space between the services which were already over-loading the frequencies available to them and those which did not appear to have commensurate needs. One of the effects of this proceeding, which actually involved a number of collateral proposals for rule-making was a reduction of the spectrum space available to the Citizens Radio Service in the 460-470 Mc band from 10 Mc to 3.45 Mc and the distribution of the remainder to a number of the Industrial Radio Services. At the same time, the

frequency band 26.96-27.23 Mc, formerly allocated to the Amateur Radio Service, was reallocated to the Citizens Radio Service, and the rules governing the latter were extensively revised. The Class A, Class B, and Class C station categories were retained, although with some revisions, and a new Class D station category was added. This new class of station was authorized to use only amplitude modulated radiotelephony on a total of 22 frequencies in the 26.96-27.23 Mc band, while Class C stations were given five additional frequencies in that area. In addition, both classes of stations were permitted the use of the frequency 27.255 Mc; Class C stations with an input power of 30 watts and Class D stations with an input power of 5 watts. It may be noted that except on the frequency 27.255 Mc, both classes of stations are limited to an input power of 5 watts. The principal technical requirement governing both classes of stations is that they use crystal control with a frequency stability of at least .005%.

The Commission's new rules governing the Citizens Radio Service and establishing the Class D category of station for the first time, were adopted on July 3, 1958, and became effective September 11, 1958. As was to be expected, there was a first slight drop-off in the rate of licensing stations in that service, due to the added restrictions on Class B stations and a change in the frequencies available to Class A stations. Also, at this time, Class A stations were authorized to use only an assigned frequency within the then available bands, rather than any frequency of their choice within the entire 460-470 Mc band. However, this reduction in the rate of licensing Class A and B stations was soon compensated by the number of Class D station licenses issued, which began modestly with a very few during October and November of 1958, but had reached 600 per month in January 1959. The possibilities for the use of Class D stations also came to the attention of a number of feature writers in the popular radio magazines at about that time, starting a series of articles on the subject that continues to the present time. This popularization has resulted in the frequency band 26.96-27.23 Mc being dubbed the "Citizens Band", despite the other frequencies available to Class A and Class B stations in that service. The discussion which follows will relate only to the Class D stations, although it should be noted that out of the 10,451 applications received by the Commission during the month of October 1960, 155 were for Class A station licenses, 205 were for Class B station licenses, and 485 were for Class C station authorizations. The remainder, 9,606, were applications for Class D station licenses submitted by applicants in all walks of life, all ages, and engaged in all types of personal or business activities from hunting and fishing to operating large service organizations, or to conducting long caravans from place to place on the public highways.

As has been noted, the present "Citizens

Band" was originally allocated to the Amateur Radio Service, and called the "eleven-meter" band, although it had been used very little by the amateurs. It was natural, therefore, that among the first licensees in the Citizens Radio Service for operation in that band there were some amateurs and some would-be amateurs, who saw in this band an excellent opportunity to become licensed on an examination-free basis and to engage in amateur-type communications and activities, including D.X. contacts whenever the "skip" conditions were right. This was encouraged, indirectly perhaps, by some of the early articles on the subject in the popular magazines as well as by some of the early advertising by set and kit manufacturers. The first of such articles appeared in March 1959 and the response from both the set and kit manufacturers and the public has been phenomenal. During the fiscal years ending July 1, 1957, 1958, and 1959, there were issued 9,329, 10,680, and 10,658 licenses, respectively, for all classes of stations in the Citizens Radio Service. Beginning with approximately May 1959, the number of Class D station licenses issued, alone, rose from 600 per month to the present approximately 5,500 per month. The total station count in the Citizens Radio Service has risen from approximately 28,000 on July 1, 1957 to 36,000 in 1958, to 46,000 in 1959, and to 126,000 in 1960. The grand total of all station licenses in the Citizens Radio Service on November 1, 1960 was 153,143, which makes the Citizens Radio Service second only to the Amateur Radio Service in the number of station licenses outstanding. Yes, there is a "Citizens Band Boom."

In retrospect at least, the reasons for the "Citizens Band Boom" seem fairly obvious. Equipment for use in the "Citizens Band" is cheaper than that available for use in any of the other services other than Amateur; it is easy to install and operate, and early any one can be licensed in the service without the requirement of and operator's license or a qualifying examination. Let us look at these reasons in detail.

First, the technical standards which apply to Class D station equipment are extremely easy to meet. Unless the equipment is "type-approved" (and there is none at the present time), the basic requirements is that it be amplitude-modulated and crystal-controlled. Specifications as to frequency stability, modulation percentage, emission bandwidth, and spurious emissions are the relaxed technical standards normally applied only to low-powered (3 watts input or less) equipment in the Commission's other land mobile services. Since the technical standards are not as strict, the equipment can be built and sold more cheaply. By way of comparison, the cost of a single transceiver unit for the "Citizens Band" can be as low as \$30.00 for a "kit" to be home assembled or \$40.00 for the same unit "ready to use", or can be as high as \$175.00 or \$200.00 for a well engineered and more sophisticated unit. Comparable equipments for use in the other land mobile services, because of the more

strict technical standards, begin in price in the neighborhood of \$25.00 and range as high as \$400.00. This difference in price, alone, could almost be taken to explain the popularity of the "Citizens Band" Class D stations among small business and industrial users of vehicular communications. Paranthetically, they are also popular for the same reason among police, fire, civil defense, and other protective and service activities in small communities where the cost of the equipment is a governing factor.

The second factor contributing to the popularity of the Class D station in the "Citizens Band" relates to the frequencies band which was made available for their use. In addition to being a band for which equipment could be easily and cheaply constructed, it is also a band in which both "whip" and "ground plane" antennas are large enough to be relatively efficient, yet small enough to be readily usable for both mobile and fixed operation. This makes the band particularly desirable for local short-distance vehicular communications and contributes to its use by individuals for personal as well as business purposes, and by local groups such as "Citizens Band Radio Clubs" as an adjunct to their social activities. This, coupled with the occasional "skip-distance" reception of distant stations has led to another form of popularity - that of radio enthusiasts findings, possibly for the first time, the thrill of communicating by radio with any number of local and distant stations, known or unknown, for no purpose other than that of making "contacts", exchanging signal reports, etc. It was the licensees who attempted to use radio as a hobby in this manner who caused operation in the "Citizens Band" to skyrocket to the point that much unnecessary mutual interference between stations was experienced. This is still happening, despite an aggressive enforcement program on the part of the Commission's field engineers and monitoring stations and new rules clearly prohibiting such uses.

Because the Citizens Radio Service was not intended, in the first place, as a radio service for hobby-type communications or experimentation, the Commission found it necessary, soon after the "Citizens Band Boom" was noticeable, to redefine the permissible communications in that service, in order to preserve it for the more serious types of use. This action was completed and made effective in March of 1960, and has had a significant effect on the amount of miscellaneous chatter and other non-essential communications observed. It may be noted that this had no appreciable effect on the rate at which applications are being received for station licenses, although the Field offices of the Commission are actively engaged in the enforcement program and numerous cases of improper use of the facilities are reported. In some cases it has become necessary to suspend or revoke station licenses previously issued, but on the whole the licensees are coming to understand the necessity for limiting their communications to serious and necessary personal or business

communications, and are finding the service extremely useful for those purposes.

As noted above, there are presently more than 150,000 outstanding station licenses in the Citizens Radio Service, over 100,000 of which are in the Class D station category, each of which represents an estimated average of more than three transmitters. When we consider that there are only 23 available frequencies in the 26.96-27.28 Mc band on which these stations may operate, the question is immediately raised as to how they are able to avoid destructive mutual interference which could easily render the service useless. Yet, it is apparent that full usage or "saturation" of the frequencies has not yet been reached, except perhaps during the hours when the hobbyists are operating in force. Applications for new station authorizations are still being received by the Commission at the rate of over 10,000 per month, and at least 60 different manufacturers are known to be engaged in large scale production and sale of sets or kits of Class D station equipment. The continued utility of the Class D stations to their respective licensees and the continued popularity of the service which has led to the "Citizens Band Boom", we believe, are due to fact that there are limitations on both station power and antenna height which hold these stations to the boundaries envisioned by the Commission when it first set up the service -- to provide a private "short-distance" radio communication facility for the use of the individual citizen in his necessary business activities or personal affairs.

The widest use of the "Citizens Band", undoubtedly, is in providing what is commonly called base-to-mobile communications for family or business purposes. For less than half the cost of a good TV set, the average family can have a base station at home and a mobile set in the car, for the purpose of maintaining contact between husband and wife, or with other members of the family, on irregular schedules or for other purposes. A TV service company can install a base unit at the shop and mobile units in its service trucks for improved service to its customers. Sets can be, and are, installed in boats, airplanes, and house trailers, on farm tractors, delivery trucks, and snow plows. In essence, Citizens Radio is being used to fill a multitude of communication needs of business, industry, and private individuals. We feel certain that it will continue to serve those needs, and that the number of stations licensed by the Commission will continue to grow for a long time to come. It does not take much of a crystal ball to estimate that the Citizens Radio Service will be larger than the Amateur Radio Service, in number of station licenses outstanding, within another year, and that it will reach at least 300,000 licensees before licensing begins to taper off. This may represent saturation in the urban areas, but not necessarily in the suburban and rural areas, where the service

will probably continue to be highly useful to all concerned.

For many persons, the Citizens Radio Service will serve or has already served as an introduction to the economies that can be effected in modern business and industry by the use of vehicular communications; to the time, effort, and mileage which can be saved through instantaneous radio communications with mobile units. It will also serve or has already served to demonstrate the extreme utility of radio communications in emergency situations in all walks of life. For many of these people, however, it will be found that once the utility of radio has been demonstrated the available facilities in the Citizens Radio Service will be inadequate, either from the standpoint of area coverage or from the standpoint of freedom from interference from other stations, particularly as the number of stations in a given area continues to increase. These licensees, having been introduced to radio for vehicular communications will want something better. It is here that the Citizens Radio Service will possibly prove its greatest utility; it has brought vehicular radio communications to all the citizens of the United States a bargain prices, it has introduced those who need it to its economies, and it has served as a stepping stone to the larger and more effective use of radio, in all of the radio services of the Commission, by the people at large. In establishing the Citizens Radio Service, the FCC has succeeded in at least one of many ways in meeting the mandate of the Communications Act of 1934, as amended, which specifies that it shall "encourage the larger and more effective use of radio in the public interest."

A TWO WAY DIAL PRIVATE MOBILE SYSTEM
FOR TELEPHONE CONSTRUCTION AND MAINTENANCE

R. L. Flaminio and W. H. Rice

Bell Telephone Company of Pennsylvania
Pittsburgh, Pa.

Summary

The assignment of frequencies by the Federal Communications Commission in 1958 for use by the Telephone Industry opened the way for obtaining more efficient plant operations through vehicular communications. The mobile communication system described in this paper was designed to serve the needs of the construction and maintenance forces in the Southwest District of the Bell Telephone Company of Pennsylvania.

The system employs decentralized dispatching which permits the supervisory personnel to use the service directly from their respective job locations. This is accomplished by incorporating the talking and signaling functions of the radio system into the standard Bell System 500 type telephone set normally used for the wire line service.

Since the dispatch points are located in administrative offices where loudspeaker operation must be avoided, mobile to base station dial signaling is employed. Similarly, dial signaling from base to mobile was used to protect the public from indiscriminate loudspeaker operation. Arrangements are also provided for mobile to mobile calls on a dialing basis. This feature is of significant value to the foremen who supervise a number of cable or line crews throughout a relatively large area.

Need for a Telephone Co. Private
Mobile Communications Service

At present, mobile radiotelephone service to Telephone Company vehicles in Western Pennsylvania is being provided on the Domestic Public Land Mobile Channels. Since these channels are for use by the general public, it is desired to limit as much as possible their use by the Telephone Company. Moreover, these channels are not well suited for communications involving work operations.

A study conducted by the Telephone Company indicated that continuous contact with telephone vehicles would save many miles of travel, reduce

circuit outage time, expedite surveys of disaster areas and reduce hazards occasioned by crosses with power company lines. It is also expected that other advantages inherent in the service would result in:

1. Reducing delays in the dispatching of two man crews.
2. Increasing the number of line crews supervised by a foreman.
3. Increasing the proportion of one man splicing crews.
4. Improving efficiency and safety in work operations generally.

General Description of the System

The area selected for the initial trial installation covers an entire district comprised of three independently operated subdistricts (See Figure 1A). One base station has been provided for each subdistrict. The Washington site is located on Mt. Wheeler adjacent to a 170 foot A. T. & T. Co. Microwave tower at a ground elevation of 1520 feet. (See Figure 1B). Summit Mountain, 2 miles southeast of Uniontown at an elevation of 2600 feet, provides the transmitter location for the Uniontown subdistrict. (See Figure 1C). The Sewickley subdistrict is smaller in area making the coverage requirements less severe. The base station is located near Sewickley on a hilltop above the Ohio River at an elevation of 1180 feet.

It was felt that a radio system to be effective for directing plant operations should provide coverage of the entire district but still permit autonomous operation within each subdistrict. Since only one radio channel is available, some degree of isolation is obtained by using separate transmitter and receiver frequencies thereby eliminating base station receiver interference from adjacent area transmitters. In addition, two frequency operation eliminates the need for push-to-talk control at the dispatch points making it possible to use the

conventional telephone instrument for both radio and wireline operation. It also makes possible the use of the base transmitter as a mobile relay station providing greater mobile to mobile coverage. Figure 2 shows a simplified schematic of the radio communication facility at one of the locations.

Frequencies authorized for the Telephone Maintenance Radio Service include assignments in the 40, 150 and 450 megacycle bands. Because of the hilly terrain and the large area to be covered, the 150 megacycle band was chosen. These frequencies provide adequate coverage and are less susceptible to long range skip interference and vehicular noise than the available lower frequencies. Moreover, the general use of the 150 megacycle band in Pennsylvania is expected to provide flexibility in the movement of vehicles during major emergencies.

It should be mentioned at this point that the present F.C.C. Rules and Regulations for frequencies below 450 megacycles in the Telephone Maintenance Radio Service do not permit the base stations to retransmit the mobile conversations. This circuit feature in the system has therefore been disabled pending consideration of a rule change by the F.C.C. However, the system will be described as designed.

The maintenance operations in each sub-district are directed by the test centers which are licensed as control points. One of the control points is shown in Figure 3. Access to the radio system is also provided through dispatch points serving the Construction Foreman, the Supervising Field Engineer and certain non-supervisory personnel. This arrangement simplifies the procedure for expanding or rearranging the control system by eliminating the necessity of modifying the F.C.C. license each time a dispatch point is added or moved.

At the present time it is common practice for systems of this kind to use loudspeaker signaling for both directions of transmission, i.e., from base to mobile and from mobile to base. Although this type of operation is adequate for many applications, it was felt desirable to use a more efficient signaling method so as to make the radio system operate as much like a wire line telephone system as possible. The communication facility is therefore available to personnel in the construction and engineering groups at their office locations. This provides the advantage of direct conversations between supervisors and subordinates.

Accordingly, two way dial signaling was provided. This permits full selective calling, direct dialing between vehicles, and group as well as individual dialing from dispatch and control points. It eliminates the disturbing effects of loud speaker operation and provides a permanent indication of unanswered calls. Since the effectiveness of two way dialing depends on full time operation of the radio equipment, a battery saver has been included in the mobile units. This modification deenergizes the mobile transmitter filaments during standby periods thereby reducing battery drain to a minimum. Consideration is also being given to providing convenience outlets in the garages and on the vehicles for use in charging batteries at night.

System Operation

A brief, general description of how the system functions may best be understood by reference to Figure 4. The radio systems in the three sub-districts are practically identical, therefore, only one of the installations will be described.

Base to Mobile

A call is initiated from a control point by operation of the transmit key located on the test desk. The closure of this key operates a relay that energizes the land transmitter and actuates the Telephone-Set Transfer Circuit. This switches the test deskman's telephone circuit from two wire operation to four wire operation. It also prepares the circuit for dialing and lights a lamp at all dispatch points to indicate the circuit busy condition. The code of the desired mobile unit is dialed. The tone generator produces the dialed pulse train which is transmitted to all mobile units. The decoder in the called mobile unit responds to these signals by lighting the call lamp and sounding a buzzer to indicate the incoming call. When the call is answered, the call light is extinguished. If the vehicle is unattended and the call is not answered, a locking relay keeps the call lamp lighted indicating a call has been received. If desired, the horn can be made to sound coincident with the operation of the buzzer.

To originate a call from a dispatch point, the handset is removed from the telephone set and the button designated "Radio" is depressed. This lights the busy lamp at all dispatch and control points and permits the user to monitor the circuit before keying the transmitter. The switch-hook exclusion key is then pulled up to operate the transmitter and prepare the circuit for dial-

ing. From this point on the call progresses as described under control point operation. Restoration of the handset after completing a call automatically turns the transmitter off and makes the telephone available for wire line service. The standard hold key is also provided to permit holding a wire line call if it is desired to answer an incoming radio call.

Mobile to Base

To contact the base station, the mobile unit operator dials the code of the control point or desired dispatch point. Rotation of the dial closes the OFF-NORMAL contacts which activate the mobile transmitter. As the dial returns to normal, the transmitter remains energized and the mobile tone generator output is interrupted by the pulsing contacts. This interrupted tone is reproduced by the base station receiver and fed to the decoder via the receive leg of the audio control line. The decoder actuates the necessary circuits to provide signaling and busy indications. After contact has been made the mobile transmitter responds to the push-to-talk button.

Mobile to Mobile

To contact another vehicle the mobile operator must dial a code to turn on the base station transmitter. Dial pulses from the mobile unit actuate a decoder at the base station which operates an auxiliary relay whose contacts operate the transmitter keying relay. The calling mobile then proceeds to dial the assigned code of the called mobile unit. The system utilizes two timing circuits to protect the base station against transmitter lock-up. The short interval timer (20 to 30 seconds) is reset each time a carrier is received by the base receiver. If no carrier is received for a 20 to 30 second period the transmitter is automatically turned off. This arrangement eliminates the necessity of a transmitter dial-off code. The long interval timer (3 minutes) is used to provide back-up protection should a foreign carrier capture the transmitter before it is released by the short interval timer at the conclusion of a call. A green lamp on the test desk key panel indicates mobile keying of the base transmitter. All mobile to mobile calls are under complete supervision of the control point which is equipped to monitor all calls.

Description of System Components

Base Station Equipment

Each base station consists of a remotely con-

trolled transmitter, a fixed receiver, a decoder, control equipment, three coaxial filters, a power meter and a ground plane antenna. Figure 5 shows the transmitter cabinet at Mt. Wheeler.

The transmitter has an output power of 60 watts and operates on a frequency of 151.985 megacycles. The receiver operates on a frequency of 158.34 megacycles. This frequency separation permits the effective use of coaxial filters so that a common antenna may be used for both transmitting and receiving. Sufficient isolation is obtained to prevent receiver desensitization.

The transmitter remote control panel contains two marginal relays normally connected in series across the control line as a full metallic circuit. The standard circuit is modified by separating the relays. One is connected from the transmit control line simplex to ground and the other from the receive control line simplex to ground, thus permitting the transmitter to be turned on or off from two sources. The relay associated with the transmit control line has its operating voltage applied through the contacts of a relay on the radio control panel which operates when a control point or a dispatch point initiates or answers a call. The relay associated with the receive control line is used to key the base transmitter on mobile to mobile calls. This relay operates indirectly from the contacts of the base station decoder which is activated by dial pulses from the calling mobile.

The timer circuit (Figure 6) was provided to comply with FCC requirements for mobile relay operation. When a mobile to mobile call is originated the mobile transmitter carrier operates K2 preparing the locking circuit for K1. Upon dialing the transmitter-on code, the decoder contacts close operating K1. Although the decoder releases immediately, K2 which is a slow release relay (20 to 30 seconds) holds K1 operated. The operation of K1 operates K3 which keys the transmitter and starts the three minute timer T1. If no carrier is received for 30 seconds, K2 which resets on each mobile transmission releases, unkeying the transmitter. If a foreign carrier seizes the transmitter during a mobile to mobile call and holds it in the keyed condition, the contacts of the timer T1, will open after a maximum period of 3 minutes releasing the transmitter.

Radio Control Panel

The Radio Control Panel is the heart of the radio system. It provides the wireline bridging

and amplifying equipment and the two way dialing units. Provision is also made for testing and monitoring. See Figures 7A and 7B.

The wire line from the radio receiver is connected through repeating coils to a telephone type amplifier, the output of which terminates in the resistance bridge. Similarly, the other direction of transmission feeds from the resistance bridge through the transmitting amplifier to the wire line feeding the radio transmitter.

The telephone repeating coils are used to derive the simplex on the transmit and receive wire lines and to match the 900 ohm cable facilities to the 600 ohm equipment.

The tone generator is bridged across the transmitter control line through the contacts of K1 thus presenting an open circuit when not in use. The decoder which has an input impedance of 30,000 ohms is permanently bridged across the receiver control line. The decoder contacts operate the station signaling equipment at the various dispatch points.

Relay "B" provides the keying voltage for the transmitter for calls originated from a control or dispatch point. Relay "A" serves two purposes; provides the transmitter keying voltage for mobile to mobile calls and completes the operating path for the "B" relay. This makes it possible for the control point to disable the transmitter on mobile to mobile calls or to preempt any dispatch point.

Dispatch Points

The dispatch points are located in the District Offices which are either in the Central Office Building or in separate nearby buildings. For reasons previously stated, it was deemed advisable to terminate the dispatch points in pickup keys of existing key telephone sets (Figure 8A) rather than provide separate consoles. This means that the same telephone instrument can be associated with a number of central office, PBX, private or inter-communicating lines in addition to the radio service with similarity of operation.

The key telephone equipment (Figure 8B) provides locked-in ringing, flashing line lamp and steady busy lamp. This equipment is mounted in a central location to facilitate cabling to the key telephone sets. If it is necessary to locate a dispatch point in a separate building, the leads required to provide the key telephone features

may be extended by means of cable plant. The pair requirements between the radio control panel and a remote dispatch point can be reduced to a minimum of two by placing center-tapped transformers at each end of the cable pairs and deriving control leads at the mid-points.

The operation of a dispatch point is as follows (See Figure 8C). To answer or originate a call the handset is removed from its mounting and the pickup key associated with the radio line is depressed. This operates the handset transfer relay which disconnects the handset from its conventional two-wire telephone network termination and connects it to the four-wire station circuit. The transfer relay also supplies ground to the dialing circuit of the telephone set and operates the "CT" and "TB" relays of the four-wire station circuit. The "CT" relay connects the handset receiver to the receive pair of the four-wire bridge in the Radio Control Panel. It also prepares a path for the transmitter keying circuit and provides a steady visual indication of the busy condition at all dispatch points. The "TB" relay supplies battery for the talking circuit and connects the handset transmitter to the transmit leg of the four-wire bridge through an impedance matching induction coil. At this point the dispatcher can monitor the radio circuit and is prepared to transmit speech when the base transmitter is keyed.

The transmitter can not be energized until a ground is placed on the keying lead through the contacts of the exclusion key provided in the switchhook assembly of the telephone set. The exclusion key can only be operated by raising it to the upper position. This feature requires definite action on the part of the dispatcher, thus preventing accidental keying of the transmitter.

Restoral of the handset returns the exclusion key to normal, de-energizing the transmitter.

The telephone set dial is prepared for functioning with the radio service by the operation of the "Radio" pickup button and restored to normal use when another pickup key of the telephone set is depressed.

Incoming calls from a mobile unit activate the decoder which signals on the appropriate output lead to operate a signal control circuit. This causes the bell to sound and the "Radio"

lamp to flash in the telephone set. An automatic time out feature is provided to prevent incoming signals from being locked in for more than thirty seconds in case the dispatch point is unattended.

Components employed to produce the necessary circuitry for the dispatch point operations are standard key telephone units, compatible in mounting and wiring arrangements to those used for normal key telephone installations. The dispatch stations are therefore conveniently accessible, simple to operate, and inexpensive to install, maintain and relocate.

Mobile Equipment

Conventional General Electric Company 25 watt mobile units equipped with internally mounted Secode decoders were used in the vehicles. The Western Electric Company 47E Control Head and Secode Mobile Code Sender are mounted on the motor vehicle instrument panel near the operator. The control head includes the power-on lamp, call lamp, handset mounting and auxiliary switch. The Secode Sender includes the dial and built-in transistorized tone generator. A Western Electric Company VJBI Junction Box is used to interconnect the units and provide the operating voltages. The junction box also houses the call bell. Figures 9A and 9B show views of a radio equipped cable repair truck.

Wire Line Transmission Considerations

Figure 10 shows a simplified schematic of the transmission circuit. Since the radio system was designed for simultaneous operation of the transmitter and receiver to permit duplex operation, it was necessary to employ 4 wire operation of the wire line facilities. The gains and losses for the two directions of transmission are shown for one of the locations.

Conclusion

The overall system performance and operating routines have not as yet been evaluated. The Washington subdistrict system has been in operation for about two months. The other two systems, Uniontown and Sewickley have only recently been completed. Furthermore, the mobile to mobile direct dial equipment, and the talk back feature has not been activated due to the F.C.C. restrictions for mobile relay operation on these frequencies. Operating experience to date has therefore been limited to normal base to mobile communications in one subdistrict.

The engineering and construction personnel in Washington subdistrict are particularly pleased with the convenience of operation made possible by integrating the radio and wire line facilities.

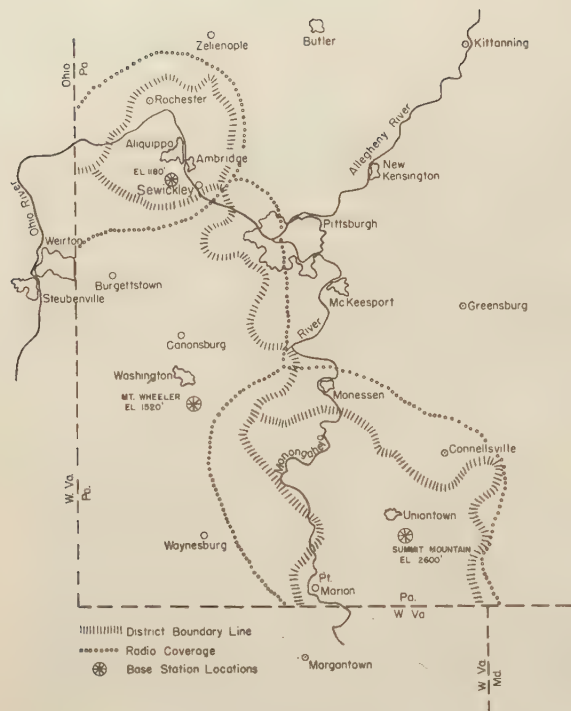


Fig. 1A - Map showing area of operation.



Fig. 1B - Washington site.



Fig. 1C - Uniontown site.

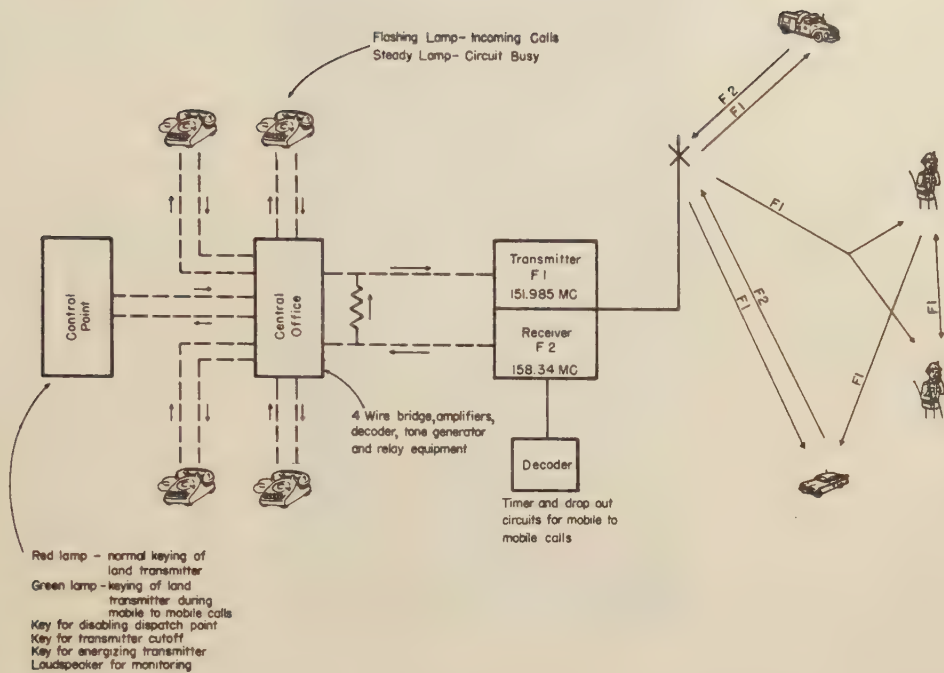


Fig. 2 - Simplified schematic of two way dial radio system.



Fig. 3 - Washington control point.

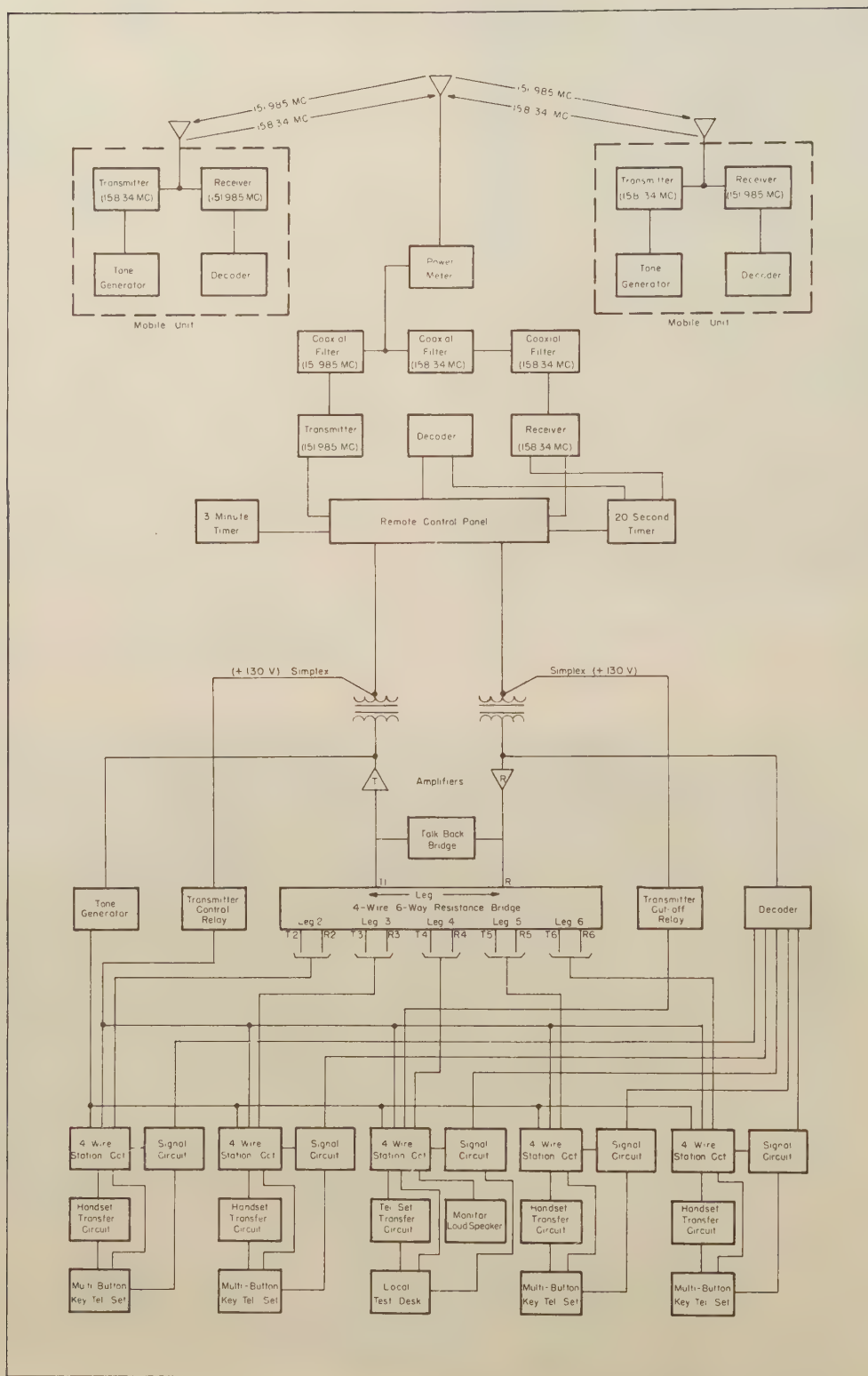


Fig. 4 - Block diagram of radio and control equipment.

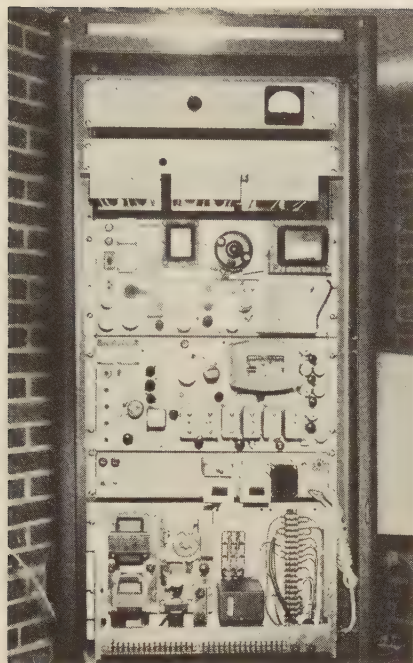


Fig. 5 - Base station equipment - Washington.

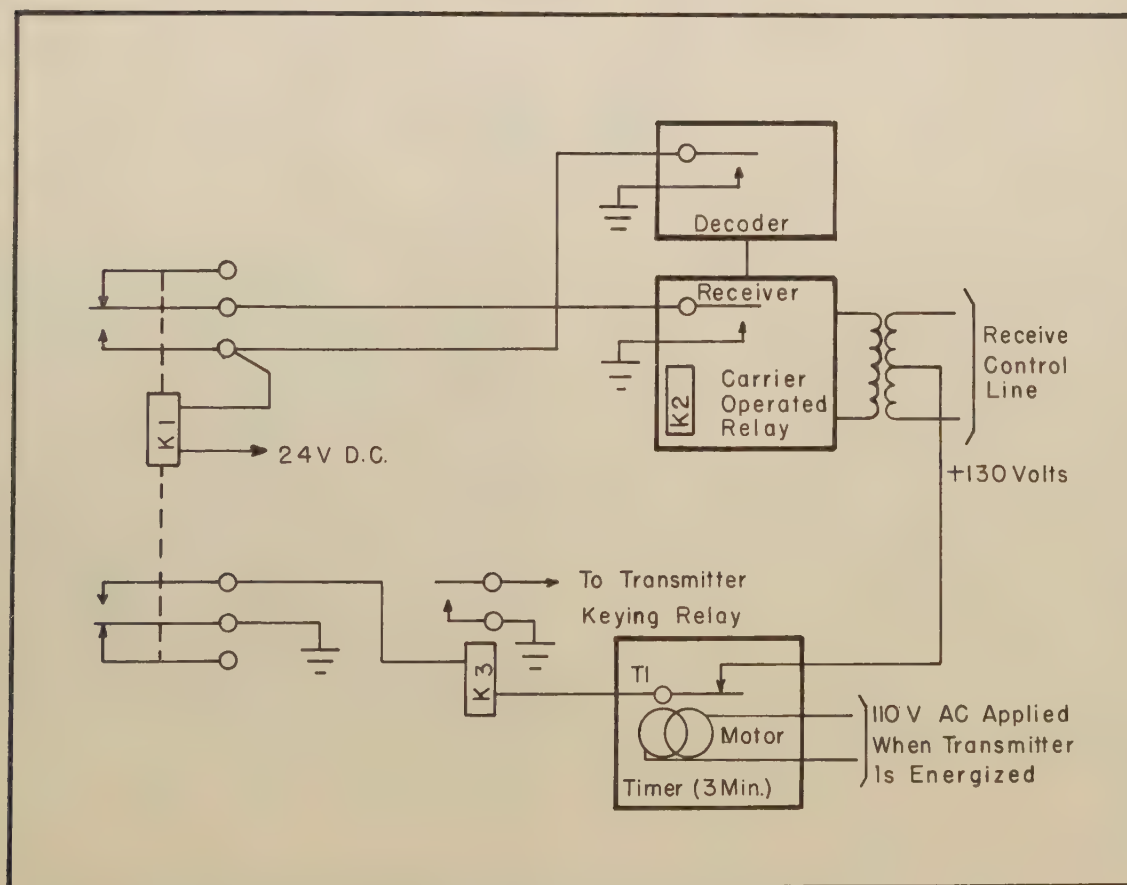


Fig. 6 - Mobile to mobile control and time out circuit.

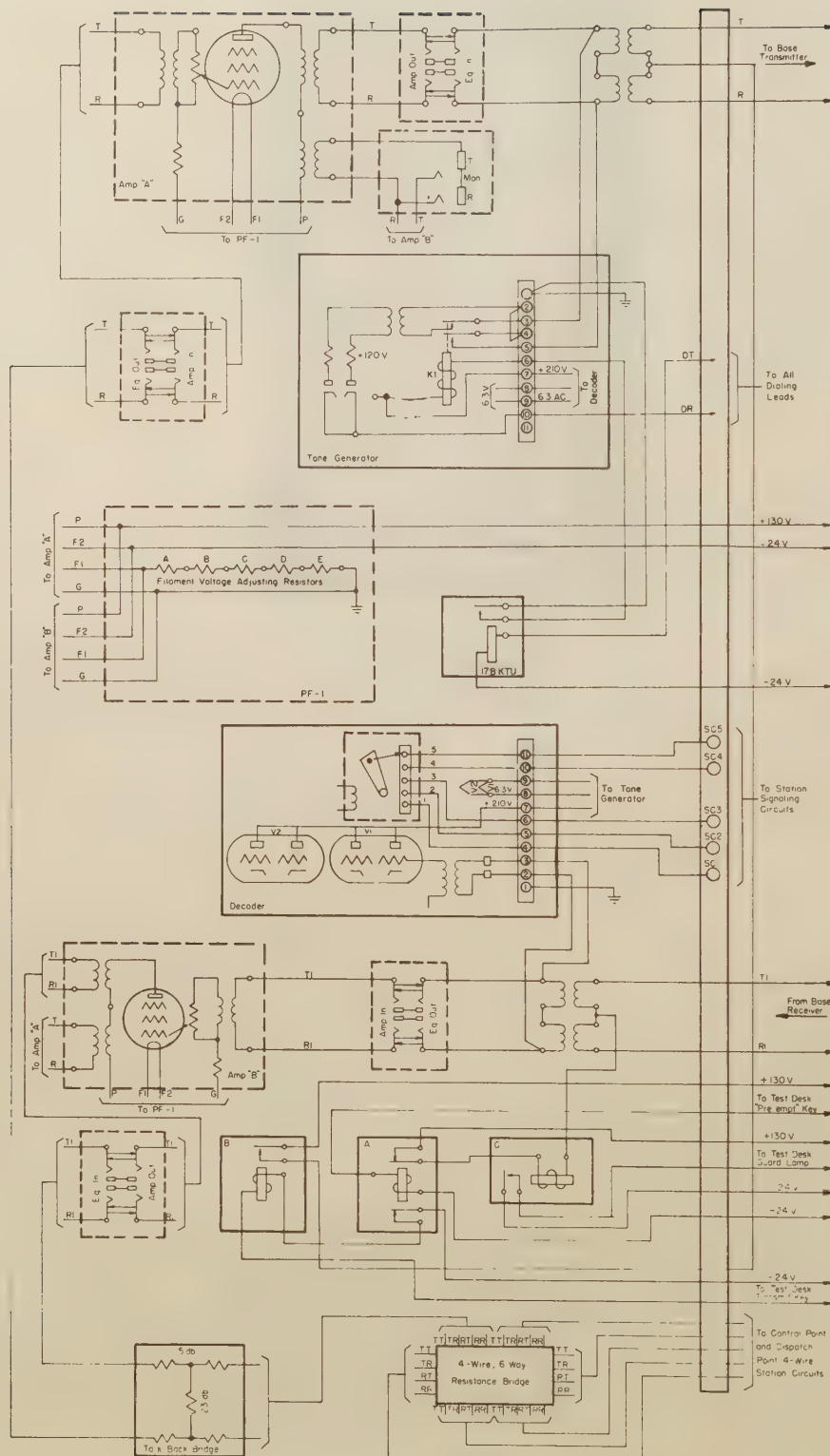


Fig. 7A - Radio control panel schematic.

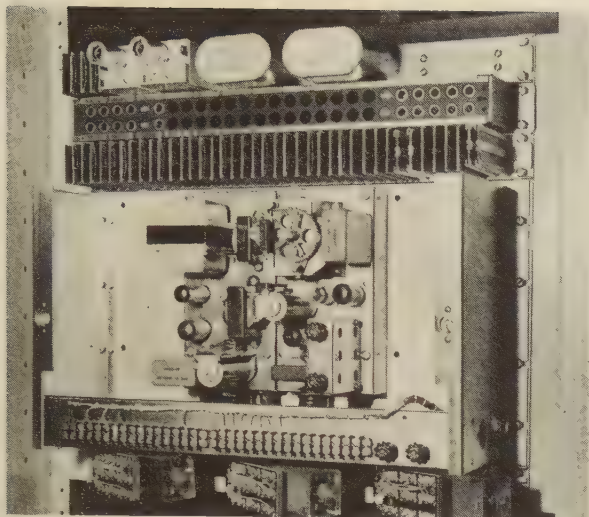


Fig. 7B - Radio control panel.



Fig. 8A - Western Electric Co. key telephone set.

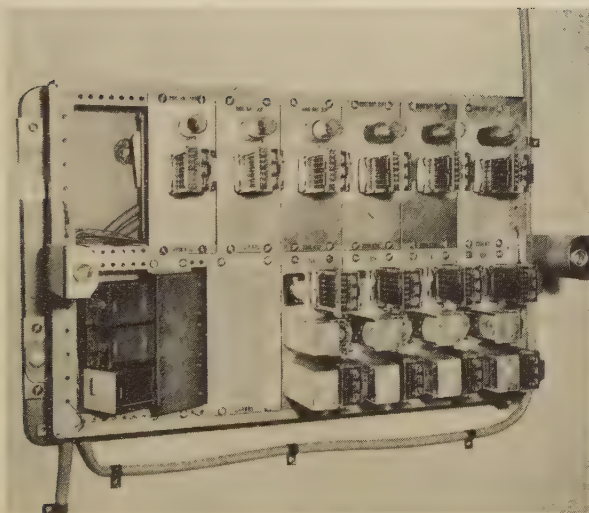


Fig. 8B - Key telephone equipment.

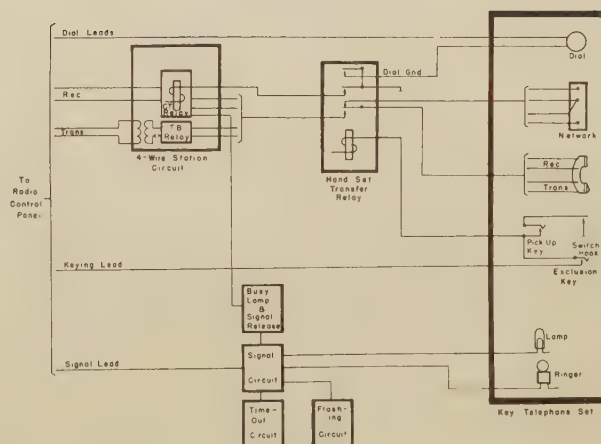


Fig. 8C - Simplified schematic of dispatch point.



Fig. 9A - Radio equipped maintenance truck

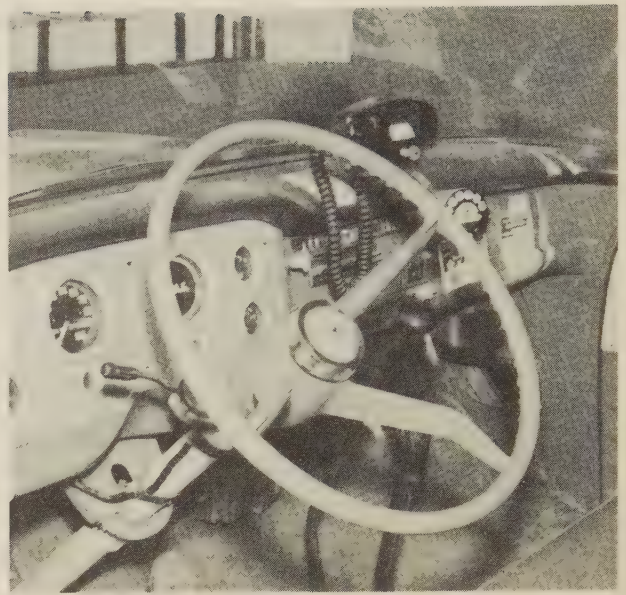
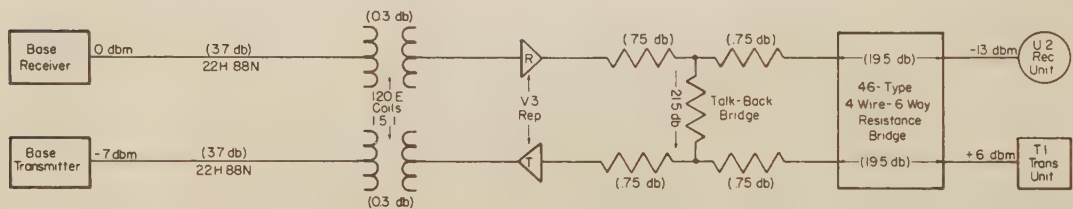
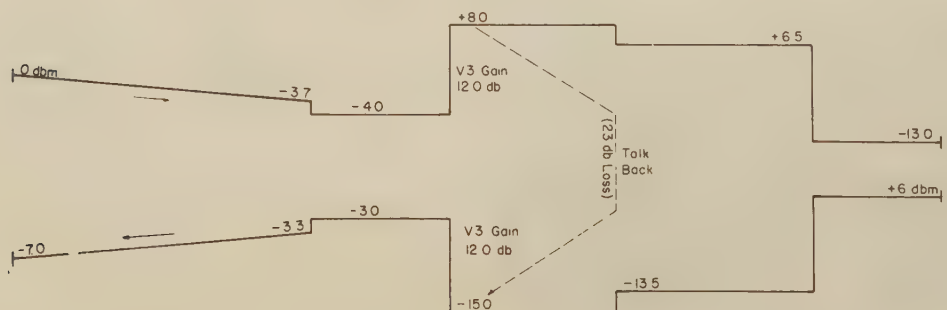


Fig. 9B - Control head and dial installation.



(Figures in parenthesis indicate losses)



	Receive Loop	
	Gains	Losses
Facility	-	3.7
120 E Coil	-	0.3
V3 Rep	12.0	-
Talk-Back	-	1.5
Res. Bridge	-	19.5
	+12.0	-25.0

Input to U2 Receiver = -13.0 dbm

	Transmit Loop	
	Gains	Losses
T1 Trans	6.0	-
Res Bridge	-	19.5
Talk-Back	-	1.5
V3 Rep	12.0	-
120 E Coil	-	0.3
Facility	-	3.7
	+18.0	-25.0

Input to Land Transmitter = -70 dbm

NOTE:
Transmission levels measured at 1000 cycles using a W.E. Co. 21A Transmission Measuring Set and a W.E. Co. 12B Transmission Measuring Set.

Fig. 10 - Transmission circuit and level diagram.

PERSONAL RADIO ANTENNAS

N. H. Shepherd
W. G. Chaney
General Electric Company
Lynchburg, Virginia

Summary

The trend toward personalizing vehicular radio sets has been accompanied by major engineering problems. Of these, one of the most challenging is that of designing an efficient antenna to occupy a small space. Due to these size limitations, personal radio antennas will be referred to as small antennas.

This paper will describe a series of tests made under laboratory conditions followed by a coverage study made under service conditions in city streets to evaluate the relative performance of small antennas and accumulate propagation data for system design.

The laboratory measurements included a study of the properties of ferrite loop antennas, coils, whips and short wire antennas. The field measurements covered actual recorded field strength data from personal carried transmitters using reference quarter-wave whips.

It was concluded that $\frac{1}{4}$ -wave whips even when working against as poor a ground plane as the set chassis offered the best performance. However, the 20 to 25 db of shadow loss found in city streets plus a 10 to 15 db antenna loss even with whips will severely restrict the coverage of personal transmitters. Other steps may be necessary if adequate areas are to be reliably covered.

Small Antennas

A small antenna is a radiating device whose largest dimension is less than one-half wave length. Its effective radiated or received power is less than that of a half-wave length dipole. This lower effective radiation means that its radiation resistance is less than its self-reactance. The ratio of radiation resistance to self-reactance is called the radiation power factor and is a measure of the antennas figure of merit. A perfect antenna, meaning all energy received is radiated, will have a radiation power factor of one. A radiation power factor of one also takes on the meaning that the energy stored in the antenna per cycle is equivalent to the energy radiated, thus no energy is carried over from one cycle to the next. In small antennas, with a radiation power factor less than

one, some energy is retained from cycle to cycle and remains in the antenna as stored energy thus limiting the amount of energy absorbed or radiated by the antenna relative to the stored energy.

A small antenna is either an electric or magnetic dipole or some combination of both. An electric dipole is one that radiates due to capacity to surrounding space becoming changed on successive half-cycles of radio frequency voltage. A magnetic dipole is one that radiates due to current in an inductance causing magnetic flux to pass through surrounding space.

Types of Small Antennas

Several types of small antennas were designed and tested to determine which gave the highest radiation power factor when used with a 150 Mc band personal receiver as normally located in a users shirt pocket. The small antennas tested fell into one of five categories as follows:

1. Earpiece cord and short wires.
2. Resonant loops.
3. High-Q ferrite core resonant coils.
4. Combination of 1 and 3.
5. Quarter-wave whip.

The earpiece cord and short wire shown in Figure 1A is basically an electric dipole. (However, some magnetic dipole effect may be produced if the cord becomes looped.) This type of antenna is an effective radiator when it is maintained in the open away from conducting and dielectric bodies and if impedances can be matched for efficient power transfer.

A resonant loop (Figure 1B) is primarily a magnetic dipole since radiation or reception is a result of magnetic flux passing through the loop.

The high-Q ferrite core resonant coil (Figure 1C) acts as a magnetic dipole for the largest portion of its radiation. An electric dipole effect adds to the vertical polarization field due to a large voltage gradient between turns of the coil.

A combination electric and magnetic

dipole is obtained by properly connecting the earpiece cord to the ferrite antenna.

Open Field Measurements

Open field measurements were made on a variety of small antennas installed in a personal receiver. To simulate actual operating conditions, the personal receiver was located in a testers shirt pocket. A modulated signal was radiated from an antenna located about 4000 feet away. The transmission path was line-of-site. The strength of the received signal was adjusted for each separate position of the tester to maintain a constant percentage readability. The percentage of readability was held to 50% by an adjustable attenuation between the base transmitter and its antenna. By using this criteria of 50% readability, a constant signal, within 1 db, can be maintained at the input of the personal receiver thus providing a high degree of accuracy in measuring antenna patterns and effective sensitivity. Instructions for maintaining the constant 50% readability was passed from the tester through a separate communications channel back to the base station operator by requesting either an increase or decrease in the radiated signal.

Representative curves of the field patterns for three of the antennas tested are shown on Figure 2. Each pattern was made by the tester rotating his position around a fixed point by successive fixed angles and directing the level of the base station power to maintain a constant 50% number recognition for random two digit numbers. The zero db reference is the average received level for each antenna and has no particular relation to the antenna efficiency. Note that the ferrite core, dotted curve, has a partial null off each end of the core which appears right angles to the facing direction of the tester. A deeper null is prevented by the electric dipole effect of the coil on the ferrite rod or near zone effects of the body. The combination of the ferrite core and earpiece cord antennas, solid line, provides a pattern which is similar to a cardioid pattern. The partial null in the back direction is due to body effects on the antenna characteristics.

The large number of test points were evaluated by using the method described above. Each test point was made in random positions and random orientation in a 100' x 100' area of relative uniform field strength. The antenna efficiency is determined by the db difference between average performance of the personal receiver antenna and a standard mobile antenna operating on a vehicle physically located

in the same field strength area. The statistical distribution, about an average for three antennas, is shown on Figure 3. An absolute comparison of each antenna with a mobile antenna is shown in the following table:

Antenna Type	PERSONAL RECEIVER ANTENNA EFFICIENCY	
	Average Loss Compared to a Mobile Antenna	Deviation from Normal
Ferrite Core & Earpiece Cord	15 db	3 db
Earpiece Cord	25 db	5 db
Ferrite Core	20 db	6 db
$\frac{1}{4}$ -Wave Whip	10 db	1 db

Open field measurements show a definite superiority of the ferrite core and earpiece cord antenna for both average loss and normal deviation.

City Street Measurements

The effective radiation measurements served to allow a comparison between antenna types and configurations. If one antenna type is more efficient then it can be assumed that the improvement will be evidenced by greater coverage, more reliable service and better grade of transmission. Relative performance is a necessary piece of data for the design engineer who is responsible for the development of associated equipment.

However, it hardly has to be pointed out that the most efficient design is not necessarily the most attractive from the packaging view. All too often, the opposite is true. Hence, the final design may represent a compromise between maximum efficiency, packaging, cost and customer demand.

The user is concerned with appearance, convenience and performance. As to the latter, his interest is in how many miles farther he can go and still talk. This is not so satisfactorily resolved in the lab.

Field strength measurements under open field conditions can be made and repeated with reasonable similarity of results. All the parameters are controlled. Now consider moving the test site to a city street. The transmission path is no longer line-of-sight. Noise is present and fluctuating over wide

limits. Moving reflectors in the form of cars, trucks, buses, etc. are constantly changing the desired signal. Conditions a foot away may be totally unrelated. What, under these conditions, do the antenna gain figures found in the lab mean?

It may be argued that propagation has been reduced to a fairly exact science for vehicular communications and that this same data can suffice for personal communications. But there is an important short-coming-propagation to vehicular equipment is not well known in city streets. Here published data gets extremely vague with figures such as + 20 db used to indicate just how crude the knowledge is. For vehicular use, this may be academic as system design generally places the base station in or near the center of the city wherein coverage is desired. Then, where problems might exist, there is maximum field strength. Coverage fringes lie out in the more rural areas where computation can be made with a higher degree of reliability.

Unfortunately, this does not hold true for personal communications. The antenna loss and low available power pull the fringe areas into the city limits - back where propagation is the poorest.

As a step toward a solution, it was decided to make field strength measurements in a metropolitan area. By recording enough data, it was hoped to gain a statistical distribution that would permit computation of results. Ultimately, an empirical relationship is sought that will reasonably permit the system design engineer to forecast personal coverage. Also, the equipment design engineer will gain a tool to tell what improvement (or loss) might be made if parameters are allowed to change.

The tests to be described were made in Richmond, Va. Two base station locations were selected, one 60 foot, the other 300 foot above street level. Both were downtown within a block of each other. The latter location was on the Central National Bank Building, the highest available building, and giving a clear and unobstructed view of the radial streets. The former was on a nearby three-story building shielded to the south and west by intervening buildings but about average roof level to the north and east. Transmission was to be from Personal Communications transmitters to the base station receiver. Figure 4 is a rough overlay of the city area showing the test points that were selected.

The base station was selected to record all data so that the pedestrian

carrying the personal transmitter could be unhampered. Tests were made only at 150 Mc. The receiver was arranged to feed the input of a pen recorded from limiter current. AGC action was disabled. Calibration was accomplished by means of a signal generator. Two ranges of sensitivity were available corresponding to an input of 0.1 to 30 microvolts and 30 to 300 microvolts. Figure 5 is a block diagram of the base station and recording layout.

The pedestrian was equipped with a 1 watt transmitter, a 100 mw transmitter and a receiver. These transmitter values were chosen as being arbitrarily convenient and available for the purpose. Each transmitter fed its own $\frac{1}{4}$ -wave whip working against the chassis as a "ground plane". In use, the 100 mw transmitter was held at face level raising the antenna to about 6 feet above street level. The 1 watt transmitter was worn on the users belt with the antenna running up past his chest. Its height was 3 feet at the base of the whip.

The test procedure required the observer to start walking at a street corner operating with one of the 100 mw transmitters. After this transmission, he would switch to the 1 watt transmitter. Then the user would switch back to the 100 mw transmitter. The base station recorded fluctuations of field strength as the pedestrian moved. In most cases the tests were continued for a full block and on both sides of the street.

All transmissions were recorded on tape and monitored aurally. The pedestrian carried a pocket receiver for two-way communications. Routes for the pedestrian were selected to include both radial streets and streets normal to the base station. Location information and any other pertinent information could be transmitted to the base station for direct marking on the tape record.

After the trial, the tapes were analyzed to determine the field strength of the recorded signals. Because of the deep and rapid fluctuations, no attempt was made to define field strength contours. Instead each transmission was broken down to the value of field strength exceeded 50% of the time (median), the value exceeded 10% of the time and the value exceeded 90% of the time.

Using this data, graphs were prepared to show the distribution of the field strength values in dbw as a function of distance. As was to be expected, the values are scattered. However, it was found for the graphs plotted that the

standard deviation was in the order of 4 db.

Curves for the median value are shown in the attached Figures 6 to 9. In plotting the curves and computing the standard deviation, consideration was given to the time base of the transmissions. As an example at a given point, say 2.1 miles, the field strength was observed to equal or exceed 2.0 microvolts 50% of the time as shown on Figure 6. This time was proportional to 0.8 inches on the tape record (8 seconds). Under other conditions at the same range, it exceeded 1.85 microvolts for .3 inches and 3.05 microvolts for .3 inches. The

average was taken as 2.2 microvolts for this distance. The curves on Figures 6 to 9 are one attempt to fit a smooth curve to the final points. From this, the standard deviation was computed.

Although corresponding graphs are not included for the 90% and 10% levels, the same procedure was followed. Results are summarized in Table I and Table II. Table I permits comparison between the 1 watt transmitter with the low antenna and the 100 milliwatt transmitter with elevated antenna when working into the 300' receiving site. Table II is the same comparison but for the 60' receiving antenna height.

Table I

dbw Received Power Level - 300' Receiving Antenna

Field Strength
Exceeded
___% of Time

90%

50%

10%

(Trans. Power)

1W

100mw

1W

100mw

1W

100 mw

Pedestrian Dist.
Miles

0.5	131	133-1/2	119	119	109-1/2	115-1/2
1.0	136	139-1/2	124	124-1/2	117-1/2	121
1.5	141	143	127	129	121	124
2.0	144	144-1/2	129-1/2	132	123	127
2.5	146-1/2	146	131	132-1/2	125-1/2	128
3.0	147	147	134	133	127	129
3.5	147-1/2	147-1/2	135	135	129-1/2	129-1/2

Table II

dbw Received Power Level - 60' Receiving Antenna

Field Strength
Exceeded
___% of Time

90%

50%

10%

(Trans. Power)

1W

100mw

1W

100mw

1W

100mw

Pedestrian Dist.
Miles

0.25	121	117	114	113	107	107
0.50	133-1/2	137	123	124	116	117
0.75	139-1/2	142-1/2	128	130	122-1/2	125
1.00	144	146	133	133-1/2	126	129
1.25	147	148	135	136-1/2	129	133
1.50	151	149-1/2	136-1/2	139	132	135

In spite of its lesser power, the 100 mw transmitter performs within about a db of the 1 watt transmitter. The 10 db loss in output power is regained by the improvement found in elevating the antenna and placing it in an unobstructed position not affected by the user's body.

If Personal Radio becomes popular, the public may have to become acclimated to seeing radio antennas on the top of hats.

Figures 10 and 11 show the results of an attempt to correlate the data in the form often used by system design engineers for coverage computations. Figure 10 is for the 300 foot receiving site and Figure 11 for the 60 foot receiving site. In both curves the 100 mw data has been raised 10 db to equate to the 1 watt transmitter. Under these conditions, the 100 mw transmitter appears to outperform the 1 watt transmitter by about 10 db. To present antenna and propagation data, it is felt that this transformation is justified.

To the distances worked, the propagation loss seems to parallel the free space, attenuation curve when working with a 300 base receiver. But when working with the 60' receiver, the loss curves begin to exhibit a 12 db/octave slope.

Figure 12 is taken from Figure 10 and 11 to show the error between the free space losses and the observed field strengths. The correction is greater in the case of the 300' location which cannot be explained. It is surmised, however, that the effective ground plane was less than the assumed 300 feet.

Conclusion

Where conditions permit operation of personal equipment with quarter-wave whips held head high, radio performance may be taken as comparable to vehicular coverage except for a 15 db antenna loss. If the antenna needs to be inconspicuous, another 5 to 15 db average system loss may result. In downtown city streets coverage will be restricted because of heavy shadow losses. Receiving locations should be selected for maximum height and line-of-sight coverage into the center of town and for low noise characteristics.

Appreciation is due to Mr. D. P. Rowley of the General Electric Company, Communication Products Department, who took care of the details of setting up the tests and who analyzed the taped data, and to Mr. Richard Jerome and Mr. Steve Szalay who assisted in conducting the

tests in Richmond, Virginia.

PERSONAL RECEIVER ANTENNA CONFIGURATIONS

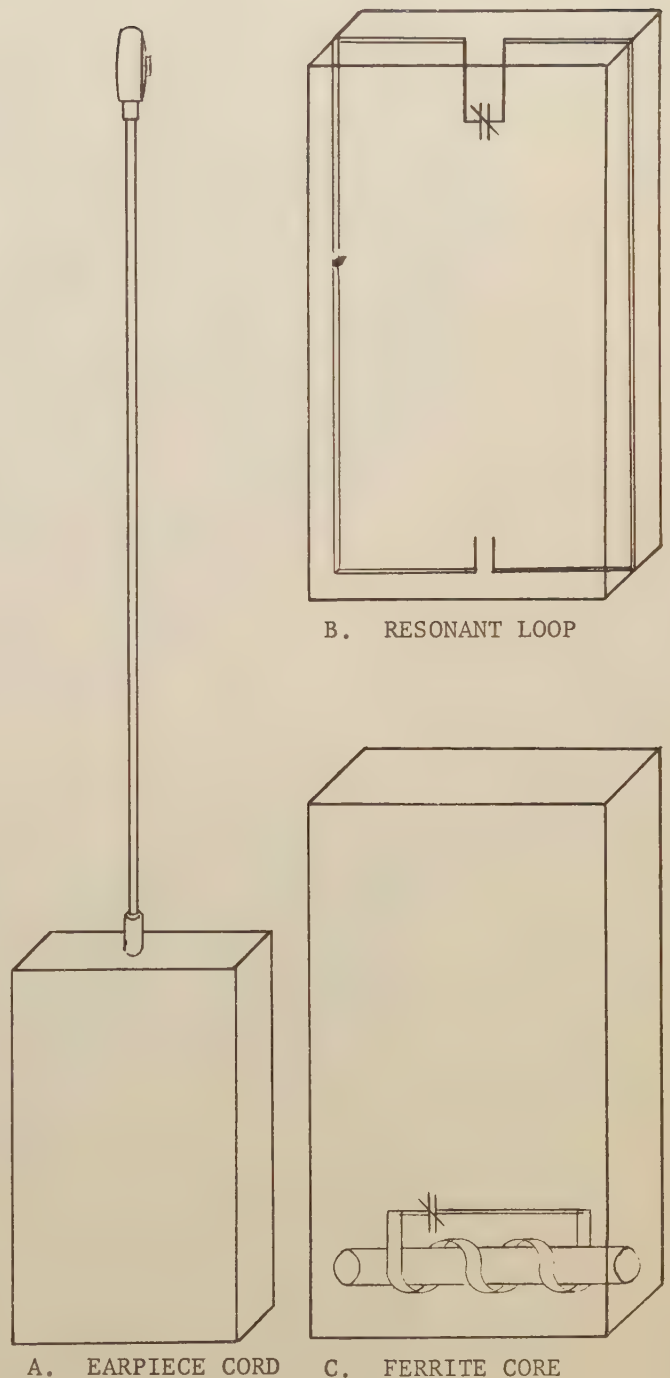


Fig. 1 - Personal receiver antenna configurations.

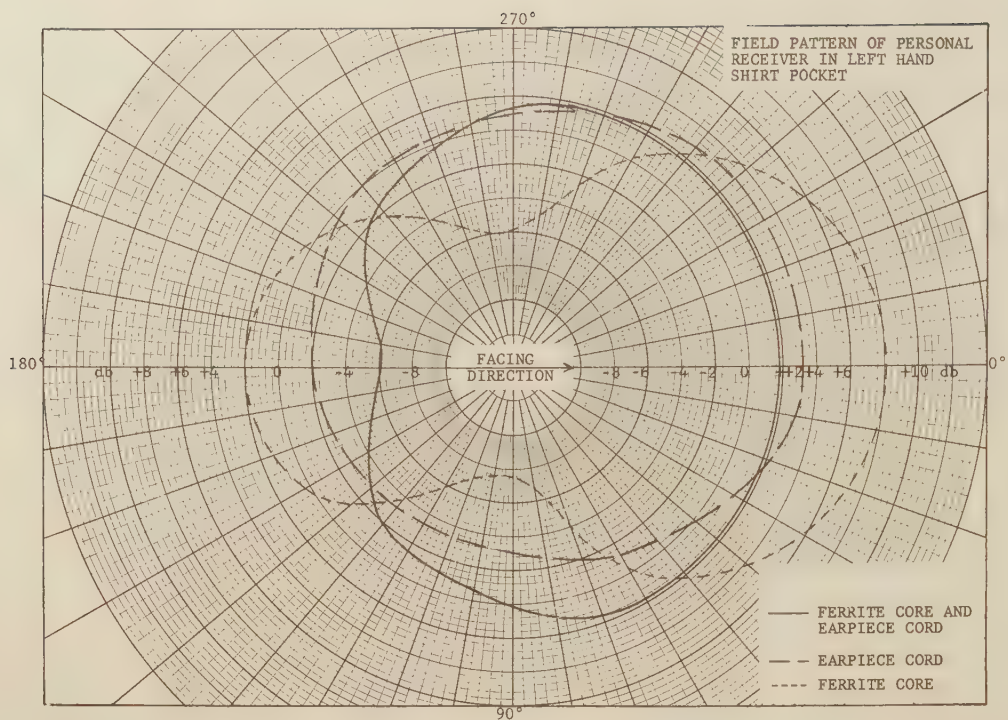


Fig. 2 - Field pattern of personal receiver in left-hand shirt pocket.

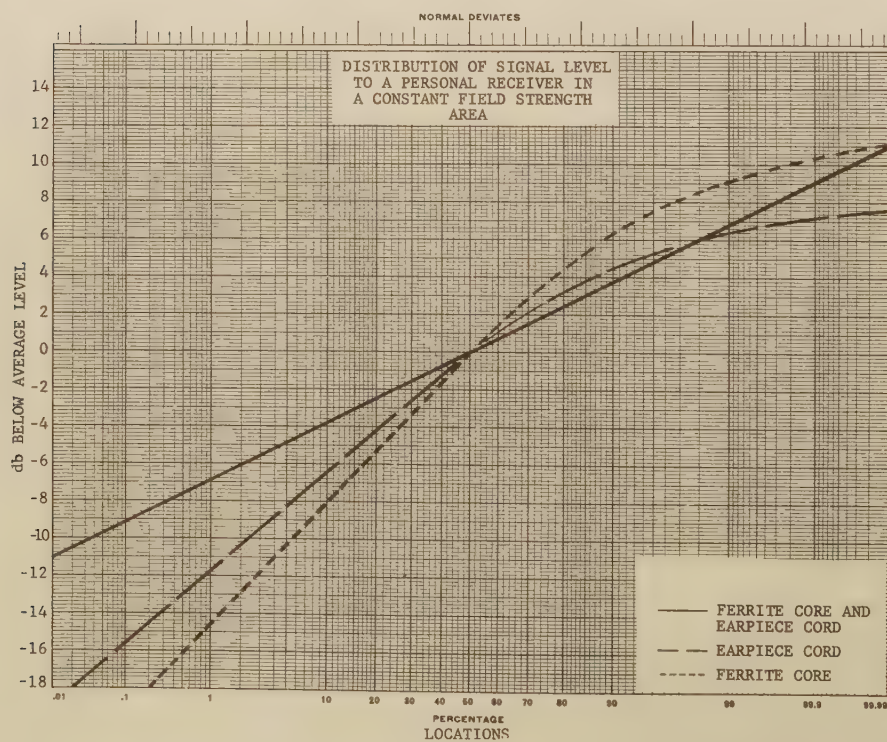


Fig. 3 - Distribution of signal level to a personal receiver in a constant field strength area.

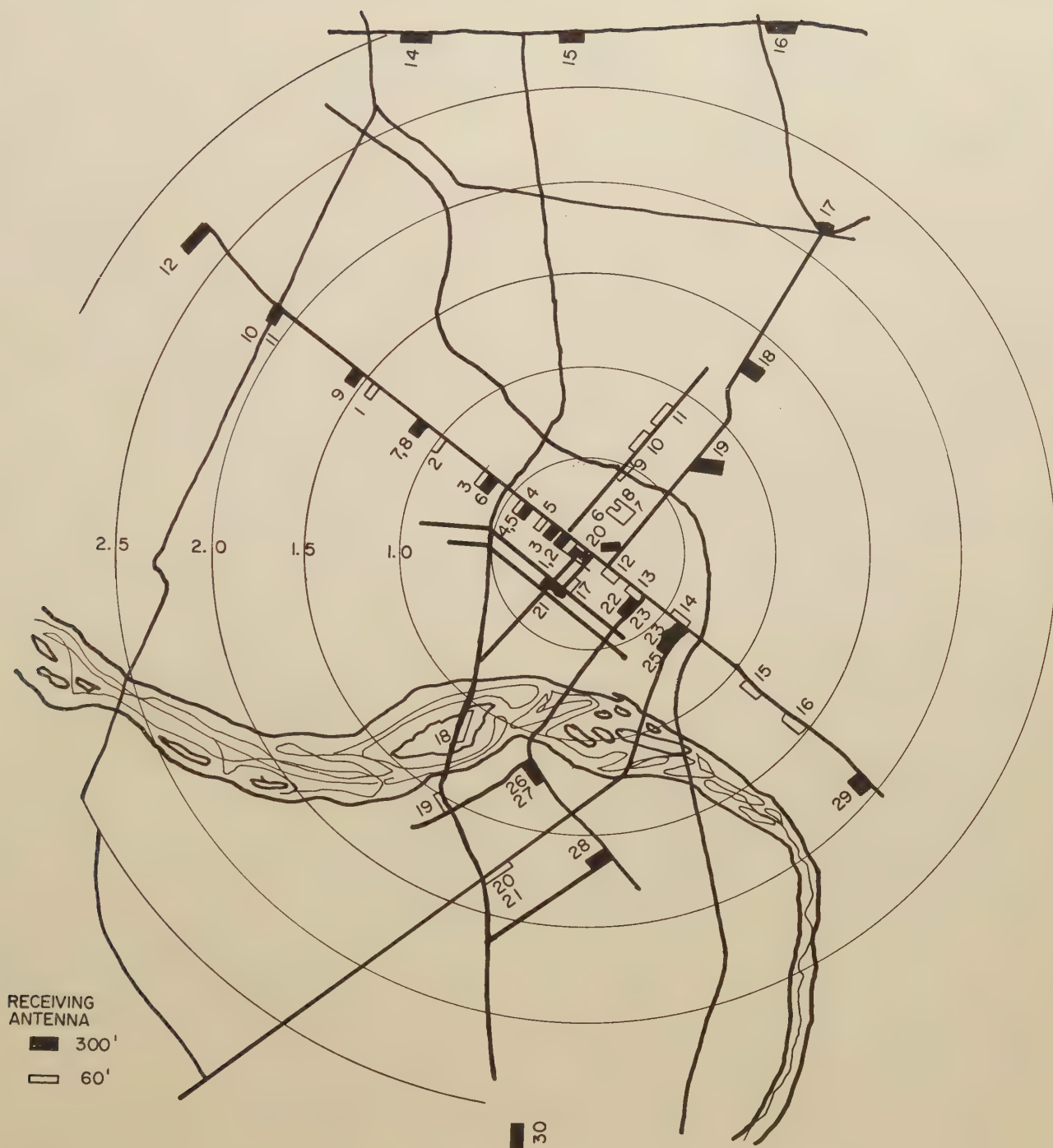


Fig. 4 - Richmond, Va., personal radio coverage survey.

BASE STATION EQUIPMENT BLOCK DIAGRAM

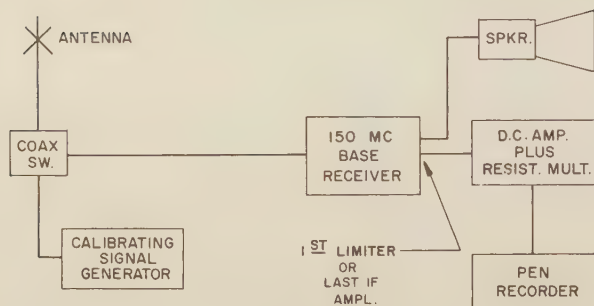


Fig. 5 Base station equipment block diagram.

PERSONAL TRANSMITTER COVERAGE STUDY

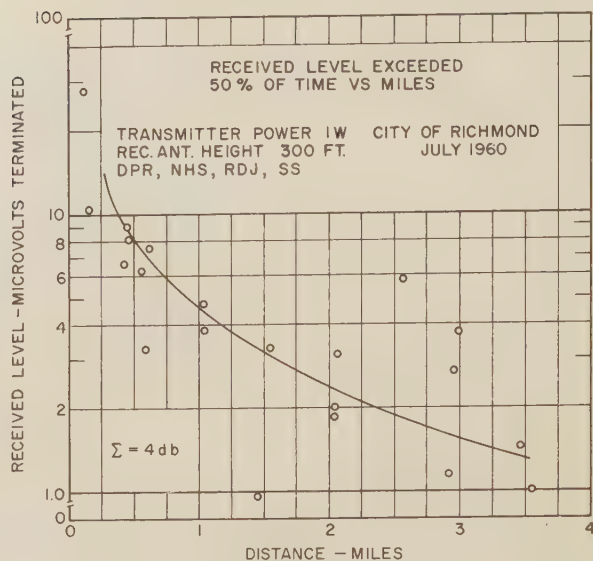


Fig. 6 - Personal transmitter coverage study.

PERSONAL TRANSMITTER COVERAGE STUDY

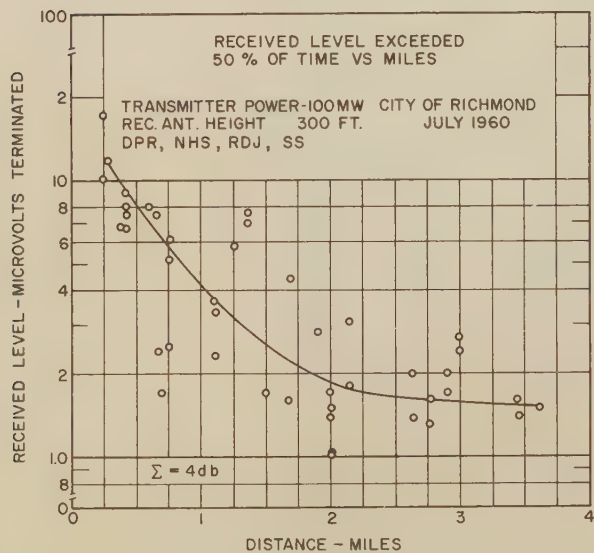


Fig. 7 - Personal transmitter coverage study.

PERSONAL TRANSMITTER COVERAGE STUDY

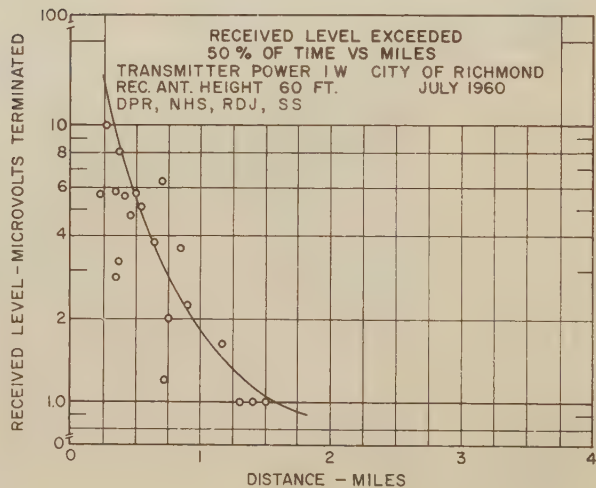


Fig. 8 - Personal transmitter coverage study.

PERSONAL TRANSMITTER COVERAGE STUDY

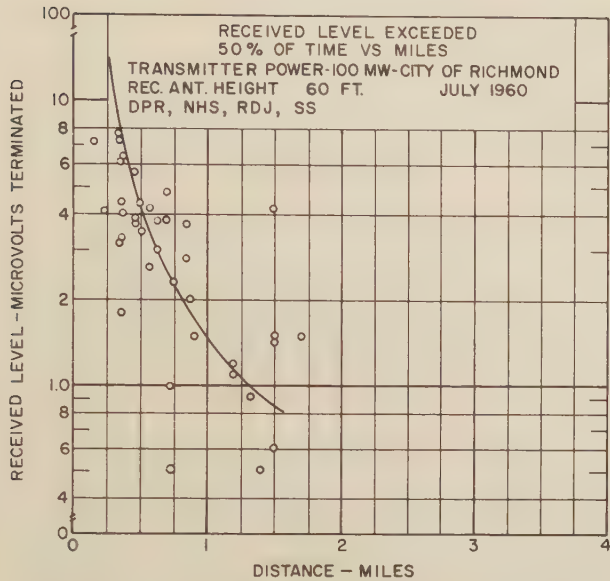


Fig. 9 - Personal transmitter coverage study.

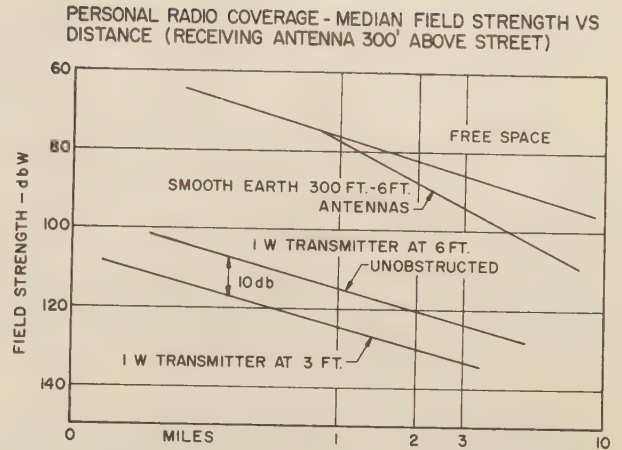


Fig. 10 - Personal radio coverage median field strength.

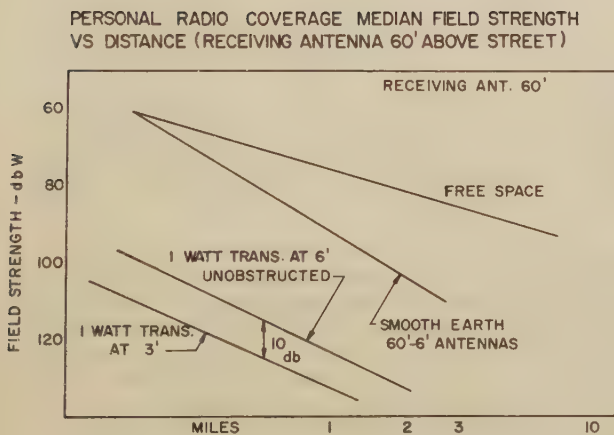


Fig. 11 - Personal radio coverage median field strength.

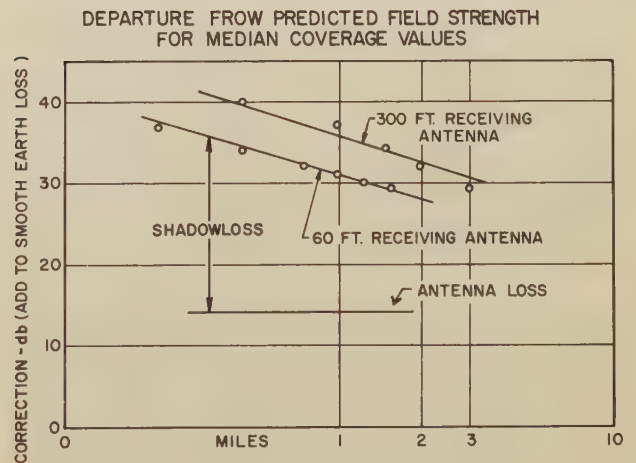


Fig. 12 - Departure from predicted field strength for median coverage values.

MECHANICAL FILTERS FOR FM MOBILE APPLICATIONS

R. A. Johnson
Western Division
Collins Radio Company
Burbank, California

Summary

The Western Division of Collins Radio Company has developed an electromechanical bandpass filter for use in the low frequency IF of split channel FM mobile receivers.

The "Mobile" Filter has a 455 kc center frequency and nominal 3 db and 60 db bandwidths of 13 kc and 28 kc respectively. The filter is fixed tuned, enclosed in a third of a cubic inch package and was engineered with the idea of low price without compromise in performance.

The Mobile Filter gives both the equipment designer and user excellent selectivity and stability, so essential when operating under split channel conditions, along with a flat amplitude response and low loss.

Introduction

Reduced channel spacing, due to increasing use of the frequency spectrum, makes more selective and stable filtering essential in mobile communication receivers. Conventional LC bandpass filters have difficulty maintaining stability, low loss and a flat amplitude response in a small package, as bandwidth is narrowed and selectivity is increased.

Electromechanical metal alloy type filters¹ do not experience these problems at the bandwidths under consideration because of their high resonant Q's and inherent frequency stability. High disk Q's result in low filter transmission loss and a flat response over a large portion of the filter passband. The frequency stability of the Mechanical Filter over a wide temperature range is excellent, while frequency shift due to ageing is practically nonexistent.

It was realized at the outset of the Mobile Program that because of the competitive nature of the vehicular communications industry, a great degree of cost consciousness must go into the filter design. For this reason, the Mobile Filter was designed "from scratch", so to say, resulting in many physical differences between it and the standard line of Collins Mechanical Filters. Also, because of the use of low loss ferrite transducers and center coupling to reduce spurious, the performance of the Mobile Filter for this application exceeds that of the more conventional Mechanical Filter types.

Operation of the Mechanical Filter

The Mechanical Filter receives an electrical

signal, converts it into mechanical energy by means of a transducer, mechanically filters out undesired frequencies, and then by means of an output transducer converts the filtered signal back into its original electrical form.

In order to discuss the above in greater detail, reference should be made to Figure 1. The electrical signal is applied to the input coil producing an alternating magnetic field that passes through the magnetostrictive ferrite rod attached to the first disk. Since a magnetostrictive material changes its dimensions when subjected to a magnetic field, the rod when properly biased will vibrate at the frequency of the impressed signal. The rod in turn drives the first disk which, by means of the short coupling tube connecting the centers of the disks, drives the next disk and so on until the signal reaches the output transducer.

Motion of the output magnetostrictive ferrite rod produces an alternating magnetic field which induces a voltage in the output coil. The effect of a material under stress causing changes in a magnetic field is called the inverse magnetostrictive effect or the Villari effect.

Both the ferrite transducer rods and the disks are resonant at the lower edge of the filter passband. The ferrite vibrates in a half wave length longitudinal mode, the disk in a two nodal circle flexural mode similar to a circular membrane, as shown in Figure 2. Since both the first and last disks and the ferrite rods are tuned to the same frequency and exhibit low mechanical impedances at the points of connection, their attachment has little effect on the modes of vibration described above.

The coupling rods between disks are less than one-eighth of a wave length long allowing them to be considered lumped elements; springs or compliances in this case. The spacing between the first two disks is reduced in order to increase the coupling between these disks. This is necessary because of the greater than half section termination provided by the end disk and ferrite combinations.

Electrical Analogy

The filtering characteristics of the Mechanical Filter can be best described by showing how they are analogous to those of an electrical bandpass filter. Probably the best known type of electrical bandpass filtering is that of

transformer coupled tuned circuits in an IF strip.

The electro-mechanical analogy that will be used is where current is analogous to force², voltage to velocity, inductance to compliance, etc. This analogy is not as commonly used as the voltage-force but equally valid.

Figures 3 and 4 show a typical transformer coupled IF stage and its equivalent circuit. The transformer has been converted to its pi equivalent, and its resistance has been brought out to the terminals to act as source and load impedances. The circuit of Figure 4 also acts as the electrical analog of the two disk filter shown in Figure 5.

The source and load resistances of the electrical analogy represent the losses associated with the transducer coils and the external electrical impedance needed to properly terminate the Mechanical Filter. In the case of the Mobile Filter, the external circuit provides approximately half of the required termination, the rest being supplied by the dissipation in the transducer coils.

The input and output ferrite transducer rod and disk combinations act like the primary and secondary tuned circuits of the analogous electrical network.

The mechanical equivalent of the electrical coupling inductor is the compliance (inverse of stiffness) of the coupling tube.

Carrying the analogy a little farther, the bandwidth of the Mechanical Filter is proportional to the stiffness of the coupling tube just as the bandwidth of the electrical circuit is proportional to the reciprocal of the coupling inductance. Increasing the bandwidth requires, in both cases, increased terminating resistance to maintain a flat amplitude response.

The lower cutoff frequency of the filters is determined by the resonant frequency of the disks in the mechanical case and the frequency of the individual tuned circuits in the electrical analogy.

Increased selectivity is achieved by adding more filter sections. In the case of mechanical filters, this amounts to very little additional loss because of the high Q of the resonant elements.

Mobile Filter Applications

The Mobile Mechanical Filter was designed for use in the low frequency IF of receivers employing split channel operation. The filter can be incorporated into new designs or used as a retrofit.

These are two external circuit requirements that must be met for proper operation of the Mobile Filter. First, the filter should be ter-

minated into 47 k Ω source and load impedances. As was mentioned before, the filter is partially terminated internally by the transducer coil. Therefore, a value of external terminating resistance is specified. Under no circumstances should the filter be externally terminated by a resistance equal to the measured input impedance of the filter. The filter must instead be terminated by resistances close to the specified 47 k Ω . The second requirement is that approximately 200 pico farads capacity be placed across the filter terminals. This includes tube, stray and wiring capacity. For best passband response, the exact value of capacity needed is that which results in maximum output voltage at 455 kc.

Because the filter is quite small, 2 inches in length by 0.450 inches in diameter, it will fit in most existing circuits. Being in a sealed container and permanently tuned, no adjustments need to be made, with the exception of the resonating capacitors on each end, to obtain a flat passband response. The permanent tuning not only eliminates the need of aligning the tuned circuits, but prevents misalignment by unqualified personnel.

Electrical Characteristics

Some of the more important electrical characteristics of the Mobile Filter are as follows:

Center Frequency:	455 kc Nominal
3 db Bandwidth:	12 kc Minimum 13 kc Nominal
60 db Bandwidth:	30 kc Maximum 28 kc Nominal
Attenuation at 449.0 kc and 461.0 kc:	3 db Maximum
Passband Response Variation:	3 db Maximum
Resonating Capacity Required:	200 pf Nominal
Source and Load Resistance Required:	47 k Ω
Input Impedance:	15 k Ω Nominal
Transmission Loss:	6 db Maximum
Attenuation of Spurious Responses from 355 kc to 555 kc:	Greater than 80 db

Filtering Elements

Development of metal alloy resonant elements with extremely low loss and excellent temperature stability has been a most significant factor in making the mechanical filter the prac-

tical device it is. The iron-nickel alloys containing 30 to 50 percent nickel have been investigated extensively because of their constant modulus properties. The most widely used material in this range is a 42 percent nickel alloy called Ni-Span C3. The chromium and titanium present in this alloy are major factors in the material's ability to achieve extremely low temperature coefficients of frequency. Mechanical filters have recently been built using special heat treated disks that have a frequency stability of one part per million per degree over the temperature range of minus 25 to plus 85 degrees centigrade. The temperature coefficient of the disks used by the Mobile Filter is monitored, but no special heat treatment is used because the comparatively wide filter bandwidth makes such extreme frequency stability unnecessary.

The extremely flat amplitude response of the Mobile Filter over a large percentage of the passband is a result of optimum filter design made possible by the high Q of the resonant disks. A typical amplitude versus frequency response curve is shown in Figure 5. Disk Q's are normally about 10,000; the exact value being dependent on the amount and type of heat treatment and/or cold work. It is interesting to note in Figure 7, which shows exploded views of the Mobile and a conventional filter, that the Mobile Filter is supported in its cover by a conducting rubber ring placed over each end disk. This lowers the Q of the end disk somewhat, but this loss is lumped in with the termination, and the filter response is unaffected.

Because of the comparatively wide bandwidth of the Mobile Filter, it was possible to use a center coupling tube in the place of conventional disk edge attached wires.

The principle advantage of center coupling is the rejection of undesirable spurious modes⁴. Spurious responses in Mechanical Filters are the result of modes of vibration of the disks other than the desired circular modes. These undesired modes all contain bending of the disk about a diametrical line or lines. By coupling the disks at a spurious node (all diameter nodes cross at the center of the disk) center coupling reduces spurious responses more than 80 db over a frequency range of 100 kc on each side of center frequency. Recent measurements indicate 100 db might be a more realistic spurious rejection figure.

The center coupling element is made of stainless steel tubing to prevent excessive bending due to shock and vibration.

Ferrite Transducers

The use of ferrite transducers has helped advance the Mechanical Filter "state of the art". The ferrite drive Mobile Filter augments the present Standard Line Filters that employ nickel alloy end wire transducers. The Standard Line has been developed to supply the need for a ver-

satile filter that operates into a wide range of source and load impedances. This capability has been made possible by the fact that the alloy end wire transducers provide almost complete self termination for the filtering elements.

The ferrite drive Mobile Filter, when designed for specific source and load impedances, more consistently exhibits better passband performance characteristics than the endwire type. The improvement in performance is a result of the ease in providing proper termination for the filtering elements. The termination is a function of the external source and load resistances and the characteristics of the ferrite transducers. Because the external resistance is fixed (47 k Ω) and magnetostrictive ferrites with small variations in their characteristics can easily be manufactured, the termination provided for the filtering elements is quite consistent from filter to filter.

Ferrite materials⁵ have a very high volume resistivity. Therefore, large diameter ferrite transducers can be operated without excessive eddy current losses. The voltage transmission loss of the Mobile Filter does not exceed 6 db, while the insertion loss is about 11 db.

The great difference in the diameter of the ferrite rod and the conventional endwire is shown in Figure 7. The large diameter of the ferrite not only makes it strong, but raises its flexural resonant frequency to a point considerably higher than the maximum frequency of vibration to which mobile equipment is subjected.

The Mobile Filter, like all ladder networks, is a minimum phase device. This, in effect, means that the filter's amplitude and phase responses are not independent. In general, a uniform amplitude response is accompanied by a uniform phase response. This also means that the sharp cutoff at the edges of the Mechanical Filter passband causes nonlinearities in the phase response at these frequencies. Since split channel deviation is 5 kc and the Mobile Filter bandwidth is 13 kc, these changes in the slope of the phase response do not present a serious problem. The phase response, because of the flat amplitude response of the ferrite drive filter, is quite linear plus or minus 5 kc from center frequency.

Mechanical Construction

The Mobile Filter is enclosed in a cadmium plated copper can, the ends being sealed by preformed epoxy resin disks. The coils, in addition to their electrical functions, prevent lateral motion of the filtering elements and support the Alnico V biasing magnet. As shown in Figure 8, the coil form is pushed against the black rubber disk assembly support. The silicone rubber support is made of conducting material, thus grounding the disks to the can and acting as a shield.

Conclusion

A special Mechanical Filter has been designed for use in Mobile receivers. Application of new engineering concepts has reduced manufacturing costs while increasing filter performance. The improved filter characteristics are a result of the use of ferrite transducers and center type coupling. The Mobile Filter, therefore, satisfies the need (created by channel splitting) for a reasonably priced high performance filter.

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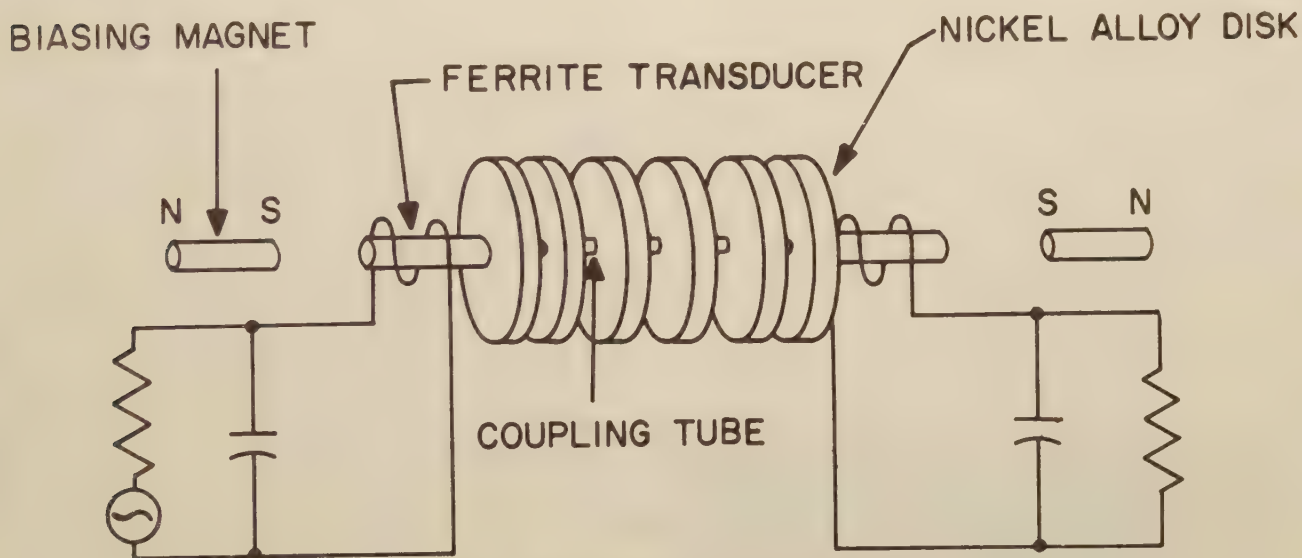


Fig. 1 - Mobile filter functional diagram.

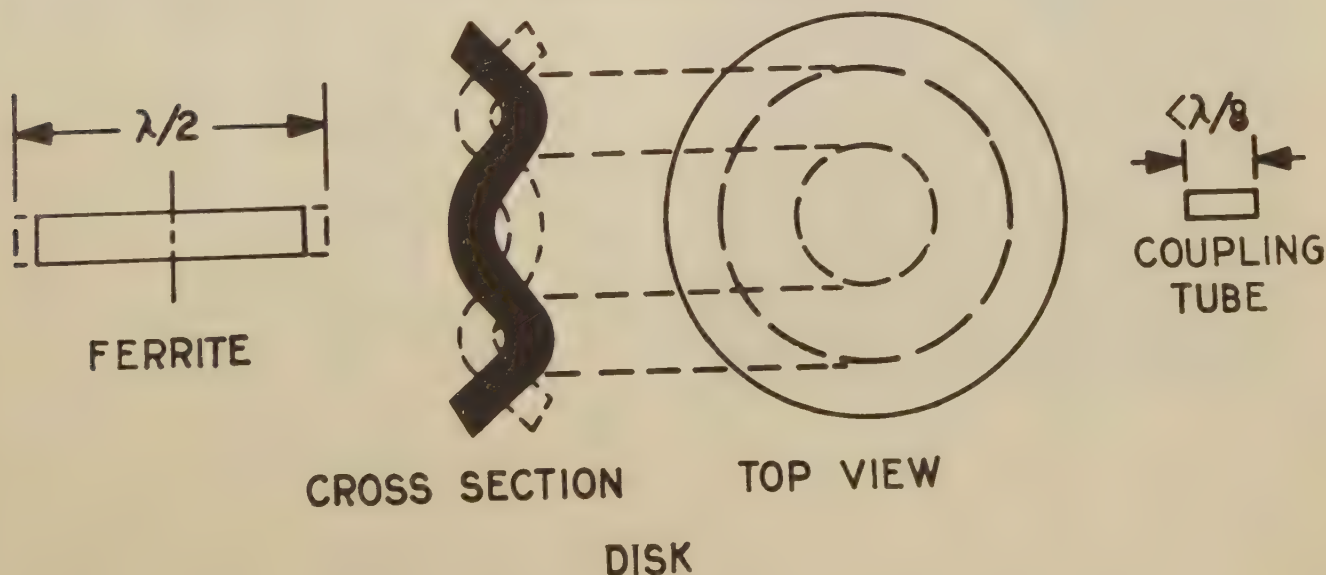


Fig. 2 - Mode of vibration of filtering elements.

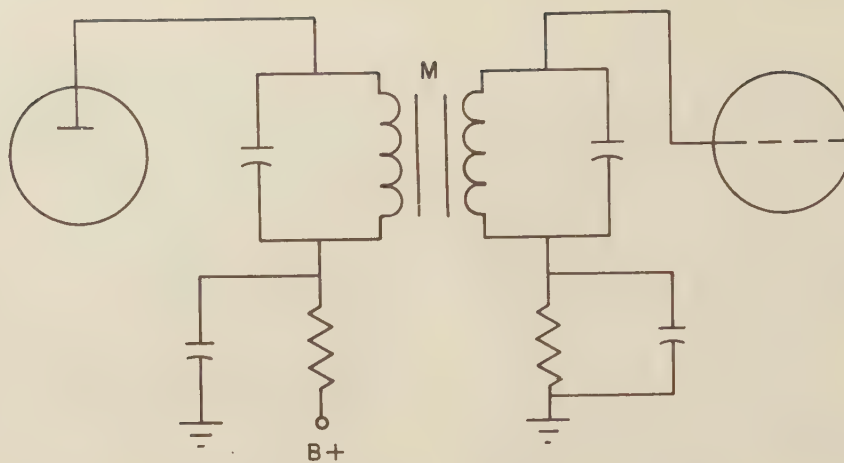


Fig. 3 - Transformer coupled IF tuned circuits.

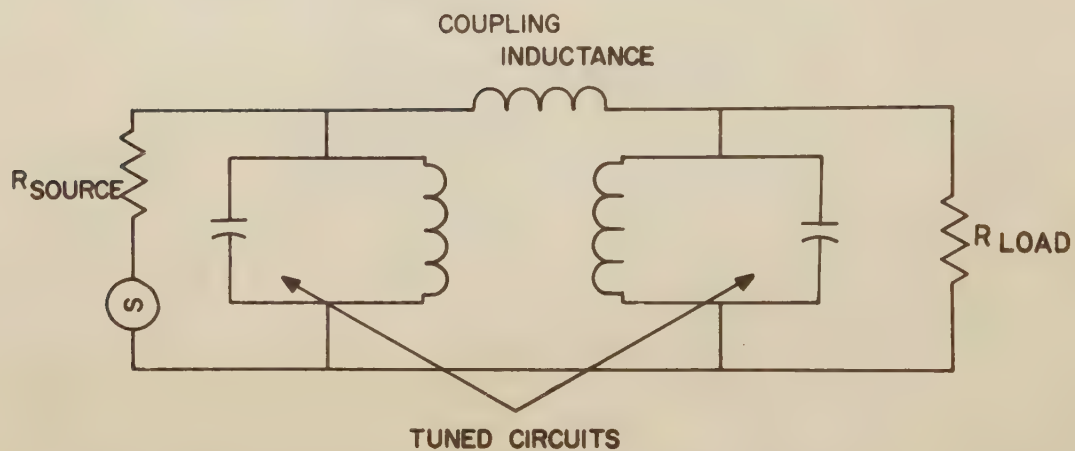


Fig. 4 - IF equivalent circuit and two disk mechanical filter electrical analogy.

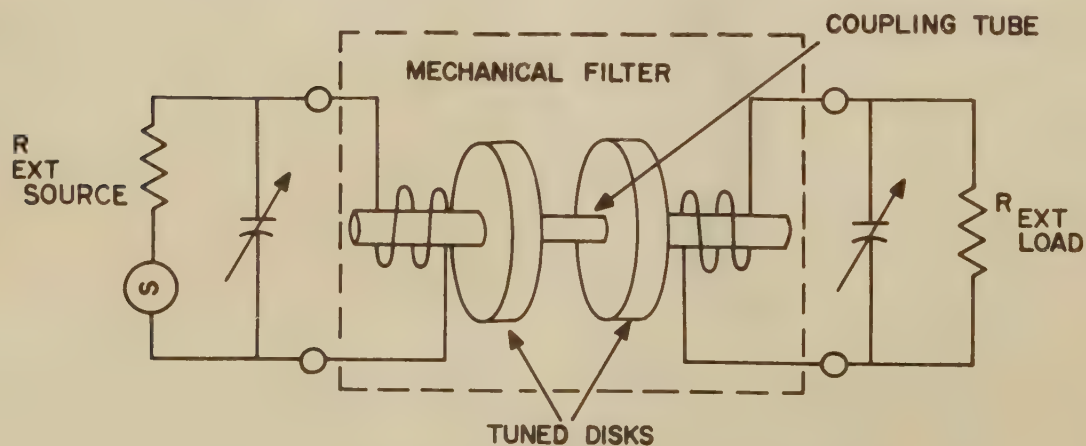


Fig. 5 - Two disk mechanical filter functional diagram.

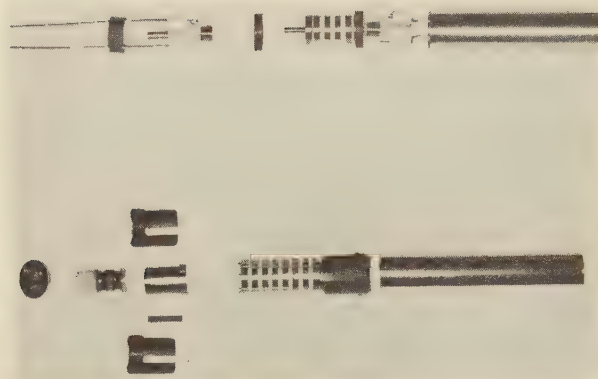


Fig. 7 - Exploded views of mobile (top) and conventional edge coupled, end wire (bottom) mechanical filters.

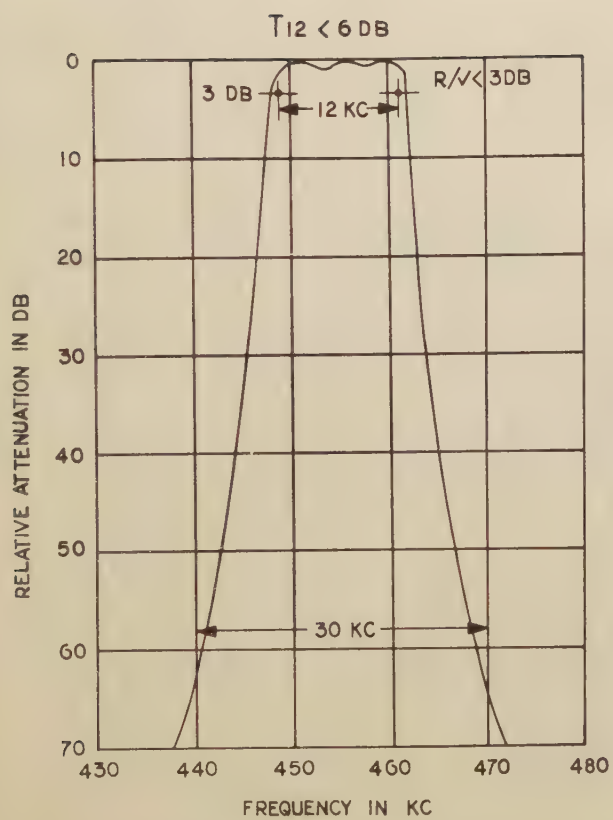


Fig. 6 - Mobile filter frequency response curve.

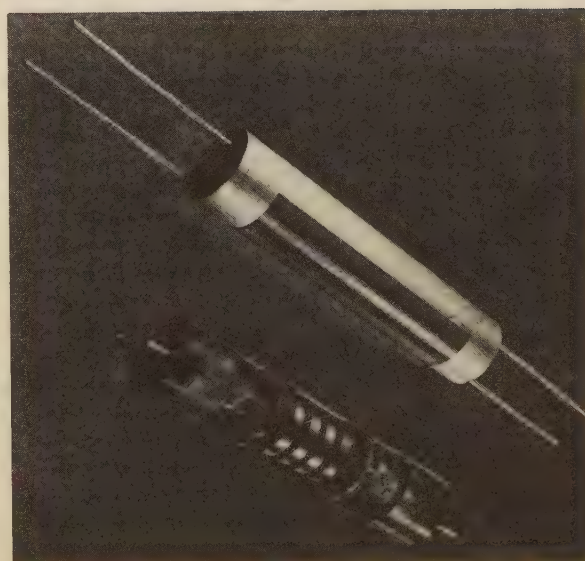


Fig. 8 - Mobile mechanical filter.

A MODULAR APPROACH TO THE DESIGN OF F.M. COMMUNICATION EQUIPMENT

B. Tennent and G. G. Armitage
Ferritronics Limited, Willowdale, Canada

Summary

Through the use of coils wound on subminiature ferrite bobbins, threaded ferrite cup cores and of newly released P.A.D.T. transistors, the I.F. strips of an FM communications receiver have been packaged into two compact, hermetically sealed, pre-tuned components. This ensures built-in optimum performance, reliability and standardisation of an important section of FM receivers for all frequency ranges and simplified maintenance.

Similar developments for other sections of FM communications equipment and for Citizen's Band Radio are referred to in this paper.

Introduction

The tremendous growth of mobile communications has recently resulted in not only the splitting in half of the adjacent channel spacings in the 50 Mc/s and 150 Mc/s bands but, also in the more extensive use of the 450 Mc/s and even the 900 Mc/s band. It has been necessary to correspondingly reduce the peak frequency deviation to the presently allowed swing of ± 5 Kc. maximum for the 50 and 150 Mc/s bands and ± 15 Kc. for the UHF ranges. Recently the FCC has authorized the use for some purposes of so-called "split-split channel" or sliver band operation with a ± 2.5 Kc. frequency deviation in the 40 Mc/s band. Channel spacings now run from 20 Kc. in the lowest frequency band up to 100 Kc. in the 900 Mc/s band.

These new regulations have increased the requirements for stability, selectivity and signal to noise ratio of the equipment which has, therefore, become more complex, diversified and critical to manufacture.

Moreover with the advent of the transistor, the demand has been for equipment which is reduced in physical size and with a lower current drain, as compared to the simpler gear it has to replace.

Consequently, we not only have tube equipment but hybridized and fully

transistorized sets. The hybrid equipment may use transistors only in the audio and power supply sections, or include all stages in the receiver except the front end.

We feel that the whole problem of designing new FM communications equipment must be re-appraised, to take into account the human factor with respect to:

- (a) standardisation,
- (b) maintenance in the field.

The purpose of this paper is to present a first approach to the solution of the above problem.

Standardisation Possibilities

If one examines the different existing designs of FM communications equipment, particularly mobile gear, it is apparent that several sections of the transmitter and receiver used in all the above applications are very similar and, therefore, readily lend themselves to standardisation. For example, in the receiver, the I.F. strip, the discriminator, the squelch circuit, audio frequency amplifier and output stage can be made practically identical for equipment to be used at all the frequency ranges with only small changes in certain elements. The same applies in the transmitter for the modulator, the oscillator, the buffer stage and the frequency multipliers. Only additional multipliers would be required for higher frequency ranges and a different output stage and power supply used in the transmitter depending on the RF power required.

However, the most striking similarity in all makes of equipment for all frequency ranges, is in the I.F. strip of the receiver. Double conversion super heterodynes are universally used and, although the first I.F. frequency may be chosen between 6 and 20 Mc/s, the second I.F. is practically always centred on 455 Kc. It is in this section of the circuitry that we have first proceeded to investigate standardisation.

Basic Techniques Used

Our first step has been to break down the functions of the elements in the I.F. portion of the circuitry into logical sub-assemblies and then to package these into self-contained individually pre-tuned compact modules. These modules are then grouped into hermetically sealed units which can be used as components of the end equipment, without any further adjustments.

The above approach has proven to be technically possible and economically sound through the use of the following new type of components and techniques. (see Figure 3)

- (a) In the filter section, coils wound with Litz wire on recently released miniature threaded ferrite cup cores and ferrite bobbins ensuring high "Q" and small leakage due to a close coupling factor between the coil and the core.
- (b) New, efficient, uniform, reliable and low priced "Post Alloy Diffused Transistors", Type 2N1515, with an average alpha cut-off of 70 Mc/s. It will be seen later that, by the use of these P.A.D.T. Transistors, the communications industry has a new, excellent and economical tool for simplification of FM equipment.
- (c) Special negative temperature co-efficient ceramic capacitors in the resonators for compensation.
- (d) Printed Wiring.

Figure 1 illustrated in block diagram the overall concept of packaging the I.F. strip into two single pre-adjusted components.

Figure 2 illustrates in block diagram the division of the I.F. circuitry into five individually pre-tuned modules which are built into the two packages.

Figure 3 illustrates the basic type of component parts used throughout to construct the modules.

Shown are:-

- (a) An assembled subminiature resonator. Size is .4"x.4"x.6". The resonator is impregnated with a silicone compound and the terminals are laid out to fit printed wiring boards.

- (b) The component parts of the resonator consisting of the threaded ferrite cup core, the ferrite bobbin wound with Litz wire for 455 Kc., a ceramic capacitor with negative temperature coefficient, which is built into the coil assembly and the mounting hardware.

The ferrite used for 455 Kc. coils is of the manganese zinc material, while for 10.7 Mc/s nickel zinc cores are used. The unloaded Q's achieved are about 150 and 100 respectively. Whenever necessary the coils are tapped for impedance matching. NPO ceramic capacitors are used for inter-coupling of the above resonators in the filters.

- (c) Germanium and subminiature silicon diodes.
- (d) Low voltage plate type 0.1 mfd. capacitors for decoupling and blocking.
- (e) Miniature deposited carbon resistors.
- (f) A CR60A sub-miniature quartz crystal at 11.155 Mc/s.
- (g) And as mentioned above, the 2N1515 Post Alloy Diffused Germanium Transistor which is used throughout the I.F. strips.

Figure 4 shows the average parameters of the 2N1515 transistor at 455 Kc. and 10.7 Mc/s for small signals. From these and from the voltage and current characteristics of the transistor, the circuit elements and the optimum matching impedances for the filters and the discriminator have been calculated.

Description of Modules

10.7 Mc/s Unit

Figure 5 shows the two modules used in the 10.7 Mc/s package.

Module A is composed of a four resonator input filter centred on 10.7 Mc/s, the R.F. transistor amplifier and a double tuned output bandpass filter. The 10.7 Mc/s centre frequency has been chosen for the first I.F. as it is high enough to ensure sufficient image rejection at the front end for the 150 Mc/s range and still enables a single 2N1515 transistor to pro-

vide sufficient gain, to more than compensate for the filter loss.

The input impedance of the filter at 10.7 Mc/s is about 5,000 ohms which provides a suitable load for the first mixer. The output impedance of the module is tapped down to about 300 ohms to match the base impedance of the second mixer.

The overall bandpass response of this module will be shown on the next slide. There is a power gain of about 12db at 10.7 Mc/s in this module.

Module B incorporates a transistorized Pierce type crystal controlled oscillator set at 11.155 Mc/s and a transistor mixer.

The voltage provided by the crystal oscillator at the base of the mixer is about .2 volts and the conversion voltage gain of the module at 455 Kc. is about 14db.

Figure 6 gives the overall bandpass response of Module A. The curve has a bandwidth of about 120 Kc. at the 3db points which is wide enough to accommodate the full frequency swing plus the unavoidable centre frequency shifts with temperature in the transmitted frequency, the local oscillator and of the filter which varies within ± 10 Kc. over the temperature range from -20° to $+60^{\circ}\text{C}$. It can be seen that the second image rejection at +910 Kc. off centre frequency is over 100db down.

455 Kc. Unit

Module C (Figure 7) is a lumped 455 Kc. filter which is made up of a tandem of ten identical permeability tuned resonators capacitively coupled with proper terminating taps at each end. The filter is basically of a high impedance type and the input is tapped down to 6.8K which provides a suitable load for the collector of the second mixer. The output impedance is tapped down to 1.5K which matches the base impedance of the following transistor stage. There are two versions of the above module:- one for narrow band; the other for wideband operation; the difference being only in the value of the coupling capacitors used and in the taps of the end coils.

In designing the I.F. amplifying and limiting stages, we had the choice between the usual way of coupling the I.F. stages by the use of separate tuned circuits for each stage, with neutralisation, or the

simpler way of coupling through R.C. networks. Experience proved that, in the first case, a stable voltage gain of only about 27db per stage could be obtained due to the high level of damping necessary. Even then, very careful layout was required to avoid oscillation problems due to the high internal feedback inherent in transistors. Using R.C. coupled amplifiers, a stable voltage gain of 34db per stage has easily been obtained without neutralisation and the units can be packaged compactly with no major difficulties.

However, it has been found that a second bandpass filter was required between the amplifier and limiter stages to reduce white noise. Without it, the inherent noise of the 455 Kc. I.F. amplifiers with their .5 Mc. bandwidth has a detrimental effect on the operation of the limiters and of the squelch.

Module D (Figure 8) incorporates the two R.C. coupled I.F. amplifiers followed by the double tuned high impedance filter with proper taps at each end.

Module E includes the two R.C. coupled limiter stages which are basically identical to the above I.F. amplifiers, but have in addition two silicon diodes at each base for limiting purpose.

This module also has the built-in phase discriminator comprised of two link coupled resonators with the associated matched pair of germanium diodes.

Again, there are two versions of these two modules depending on whether they are to be used for wide or narrow band operation, the difference being only in the value of the coupling capacitors in the filter and discriminator and in the location of coil taps for suitable impedance matching. Each stage of the 455 Kc. amplifier is separately decoupled from the B+ by R.C. networks connected in cascade to avoid interaction through the internal resistance of the supply line.

Figure 9 shows the gain characteristic of each of the R.C. coupled I.F. amplifiers. It can be seen that a stable voltage gain of over 60db is obtained, from a pair of transistors, at 455 Kc.

Overall Performance

Figure 10 shows the packaging of the modules into two components. This layout can, of course, be modified to meet individual requirements.

Figure 13 shows the two packages supplied as components ready for incorporation in a receiver chassis.

The sizes of the units are respectively:-

10.7 Mc/s - $3\frac{1}{4}$ " x $1\frac{1}{4}$ " x $1\frac{1}{4}$ "

455 Kc. - $6\frac{1}{2}$ " x $1\frac{1}{4}$ " x $1\frac{1}{4}$ "

Total current drain at a battery voltage of 12.8V is below 9 mA.

Only four solder joints are necessary to connect each package.

The circuitry is off ground so that supplies with positive or negative ground may be used.

The packages are hermetically sealed with a silicone adhesive in such a way that they may be readily opened at the factory for repair, should this become necessary, and yet cannot be opened in the field by unauthorized personnel.

Figure 11 is an overall selectivity curve of the narrow band version.

The acceptance band is about 13 Kc. at the 6db points, whilst the rejection at ± 15 Kc. is over.

There is no re-entrance in the attenuation curve on either side. The centre frequency stability with temperature over the range -20° to $+60^{\circ}$ C. is within ± 500 cps of the nominal, which is factory adjusted within ± 250 cps of 455.000 Kc. at room temperature.

Figure 12 shows the amplitude versus frequency response curve or the "S" curve for a narrow band unit. It can be seen that the slope is about .4 volts per Kc. The distortion on a dynamic test is below 2% for a 1000 cycle tone. The voltage gain of the I.F. strip is above 100db and full limiting is achieved by an input signal of about 1 millivolt. A total of only seven transistors is used in the two units.

Further Developments

As mentioned earlier, the same type of approach can be applied to other elements of FM communications equipment.

For instance, we are presently working on a packaged audio unit composed of the following modules.

(a) The squelch circuit consisting of:-

- (1) A high pass filter.
- (2) Noise operated amplifier.
- (3) Diode voltage doubler.
- (4) D.C. amplifier.

(b) The audio pre-amplifier activated by the above squelch circuit and incorporating the de-emphasis network.

(c) An audio output stage equipped with two transistors connected in a sliding bias arrangement through a Zener diode.

Also, there is the modulator unit. This will incorporate a three stage transistor audio amplifier with an automatic deviation limiter, a 2000 cps low pass filter and the pre-emphasis network.

The approach to construction of FM communications equipment as just described can also contribute greatly to the reliability of essential and emergency services through the redundancy conception.

The various packages can easily be paralleled and switched by means of relays, while the miniature size of the units still enables production of moderate size equipment.

A recently developed micro miniature mercury relay has been successfully used to switch elements at 150 Mc/s.

An additional possible application of the two components shown is for field conversion in a matter of minutes of existing wideband tube type mobile gear, into ready to operate, narrow band, hybrid units at an economical cost.

Citizen Band Radio

Although it is somewhat outside the scope of this paper, being AM rather than FM, we would like to add a few words on Citizen Band Radio in view of the tremendous boom. Here again, there are many types of equipment already available - some tube, some hybrid and some fully transistorized - and we feel that standardisation of at least some parts of the circuitry is essential, if servicing of the equipment in the future is not to be chaotic. This is especially true in view of the large potential usage with the majority of the users completely non-technical. The FCC regulations already

Conclusion

specify that the transmitter-oscillator must be factory calibrated, sealed and guaranteed to within .005%. We have practically completed a modular package of the I.F. strip using double conversion super heterodyne for a Citizen Radio receiver, the most common circuitry used.

This package consists of a double tuned bandpass 1st I.F. filter centred on 4.3 Mc/s, a crystal controlled oscillator-mixer stage, followed by a 4 resonator 455 Kc. second I.F. filter, a 455 Kc. amplifier and detector stage. The unit uses the same 2N1515 transistors and component parts as the FM packages. It has a bandwidth of about 5 Kc. with a rejection of 40db at ± 10 Kc.

As far as the transmitter is concerned, an approved unit including a crystal controlled R.F. oscillator with a buffer stage is presently available from sources in the U.S.A. This is pre-adjustable over the 27 Mc/s band.

To conclude, we feel that the modular approach to the design of FM communications equipment we have followed in our presentation would permit:-

- (a) The standardisation of important sections of the circuitry common to practically all F.M. sets and independent of the frequency band used.
- (b) A smaller overall equipment size and weight with reduced current drain.
- (c) An improved stable performance in the field with closer tolerances on the assigned frequencies, and best obtainable "Sealed-In at the Factory", selectivity, phase linearity and intelligibility.
- (d) Servicing problems in case of failure drastically reduced with a minimum of test equipment and skill required, and no chance for error in readjustments.
- (e) A simple and economical way to provide "built-in" reliability, for Emergency, Public Safety and Military Services, by parallel redundant module construction with an automatic relay changeover.

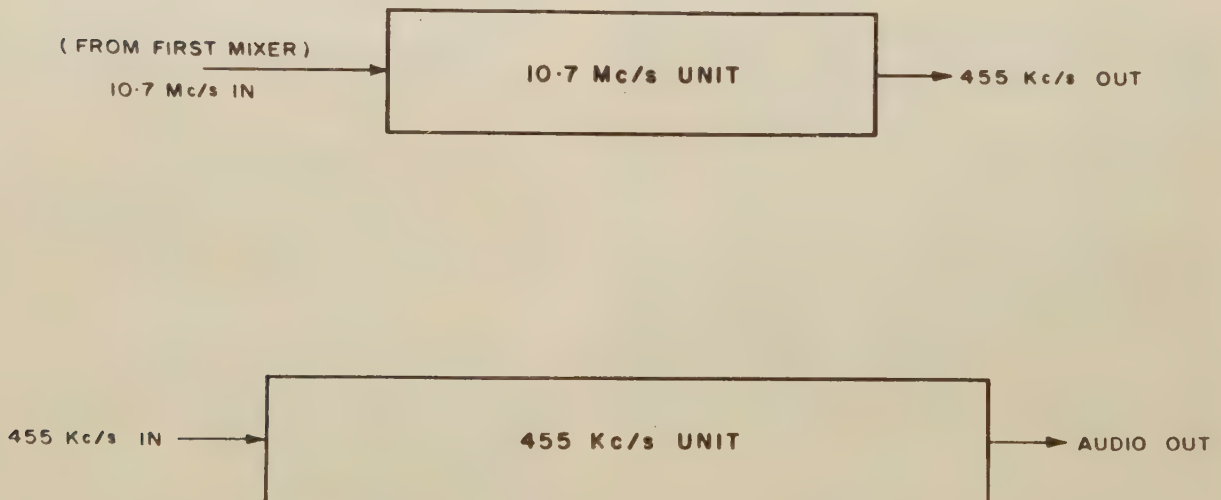


Fig. 1 - IF strip block diagram.

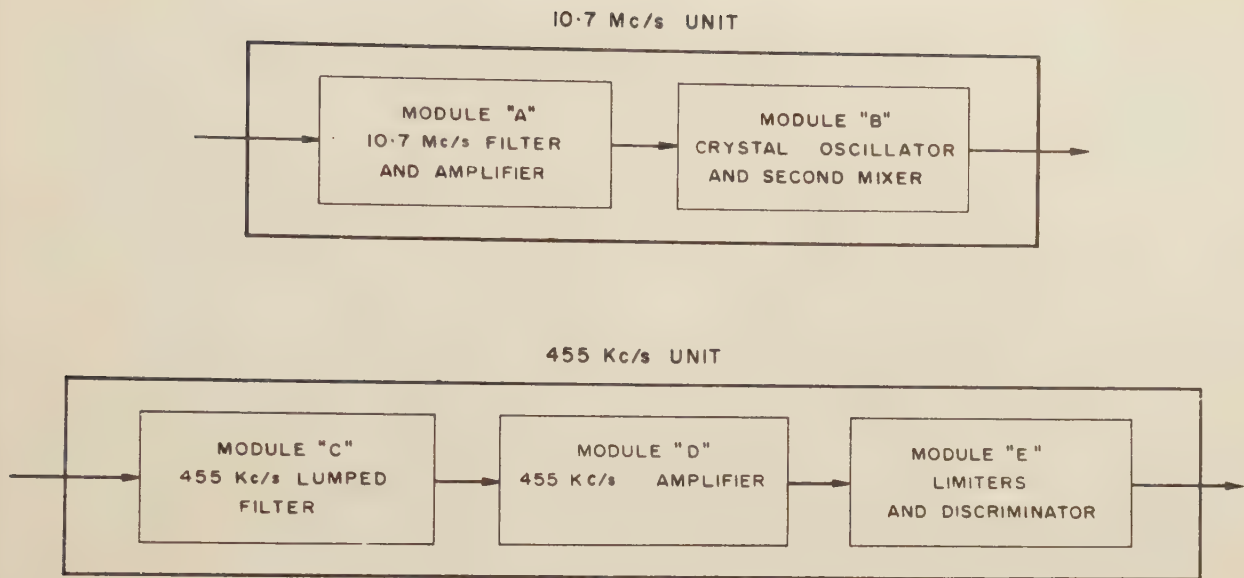


Fig. 2 - Module packaging block diagram.

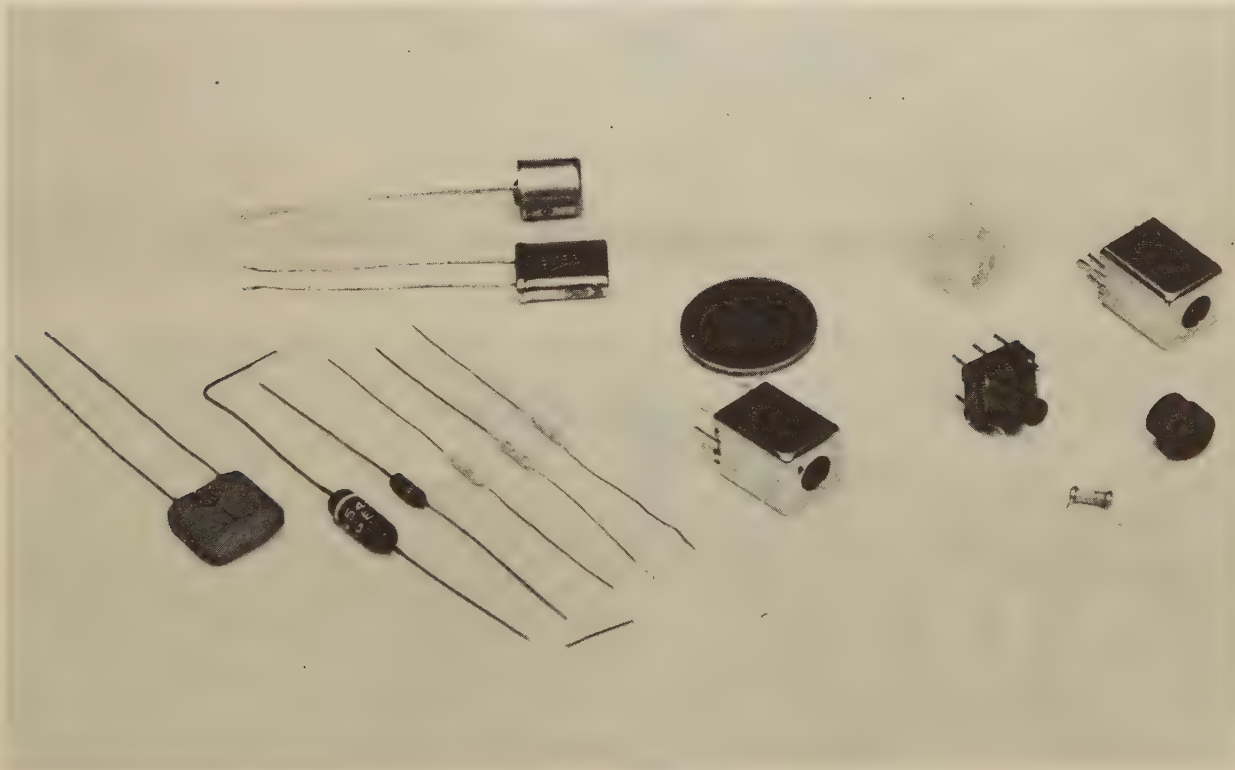
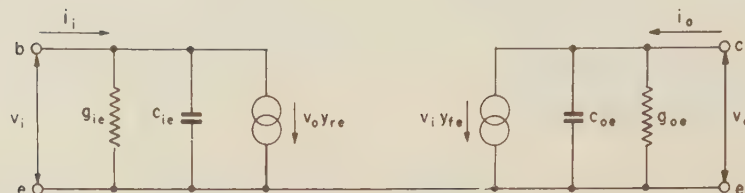


Fig. 3 - Illustration of components used.

2N 1515 TRANSISTOR
 SMALL SIGNAL PARAMETERS (at 25°C)
 WITH V_{CE} 6 VOLTS
 I_E 1 MA



AVERAGE VALUES		
	455 Kc/s	10.7 Mc/s
R_s	200 Ω	150 Ω
f (NOISE FACTOR)	3 dB	5 dB
g_{ie}	4 mA/V	3 mA/V
c_{ie}	80 pF	60 pF
$-g_{re}$	1 μ A/V	1 μ A/V
$-c_{re}$	1.8 pF	1.8 pF
y_{fe}	36 mA/V	27 mA/V
g_{oe}	7 μ A/V	90 μ A/V
c_{oe}	7 pF	5 pF
GAIN	61 dB	28 dB
y_{fe}/y_{re} (STABILITY FACTOR)	7059	270
STABLE GAIN (SAFETY FACTOR 4)	33.3 dB	19.1 dB

Fig. 4 - Small signal parameters of 2N1515 transistors.

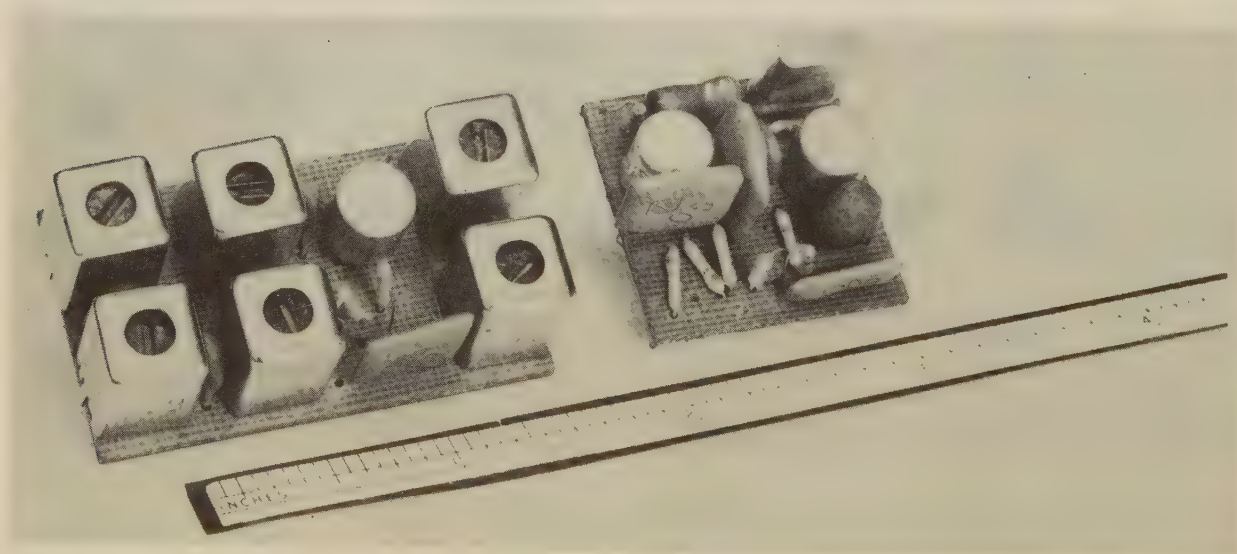


Fig. 5 - Sub-modules A & B.

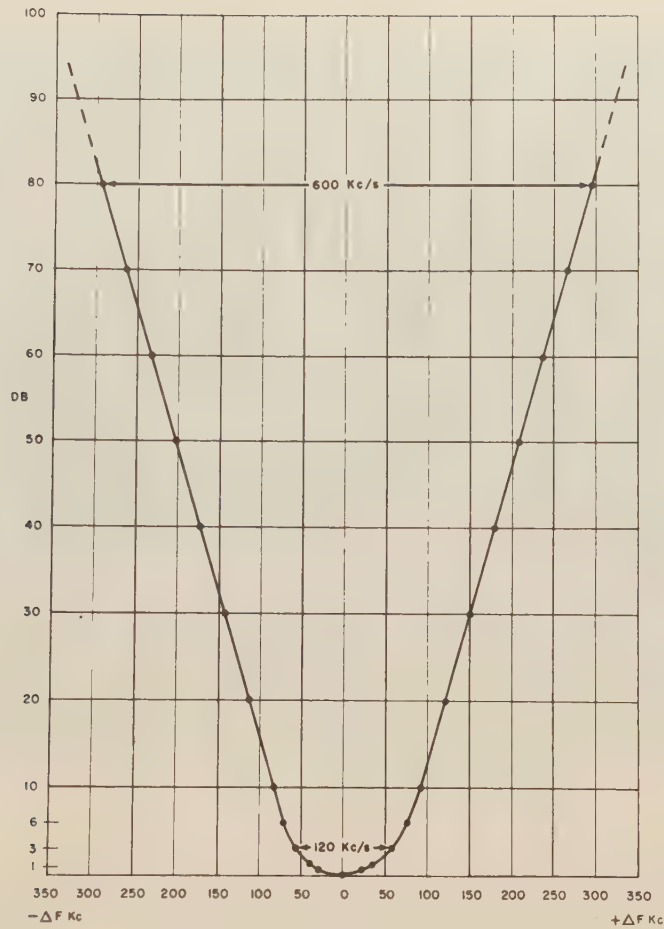


Fig. 6 - Bandpass curve of 10.7 Mc/s unit.

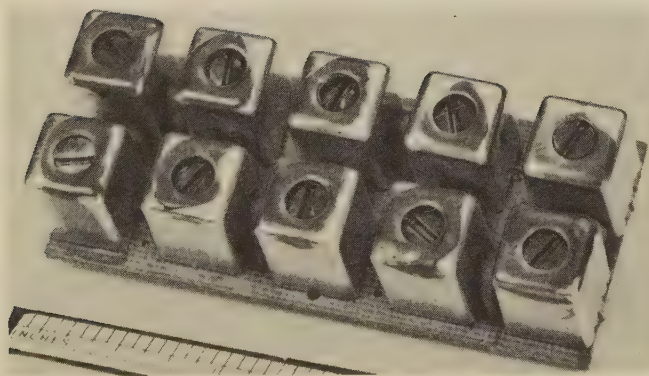


Fig. 7 - 455 Kc lumped IF filter (sub-module C).

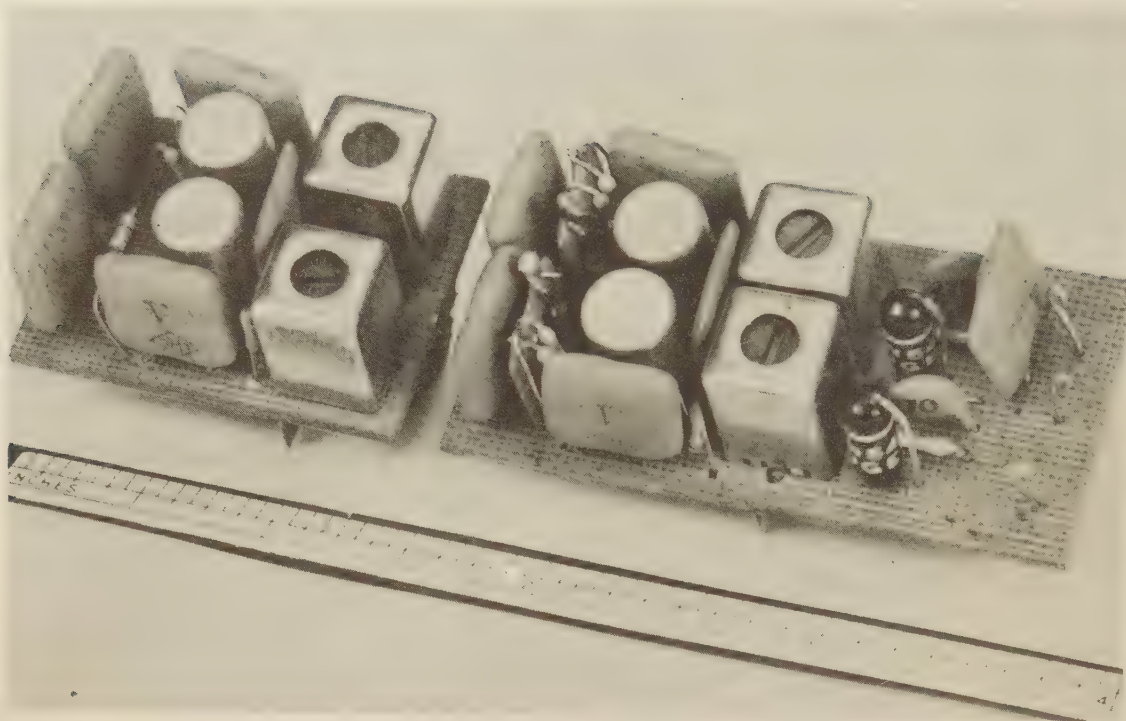


Fig. 8 - Sub-modules D & E.

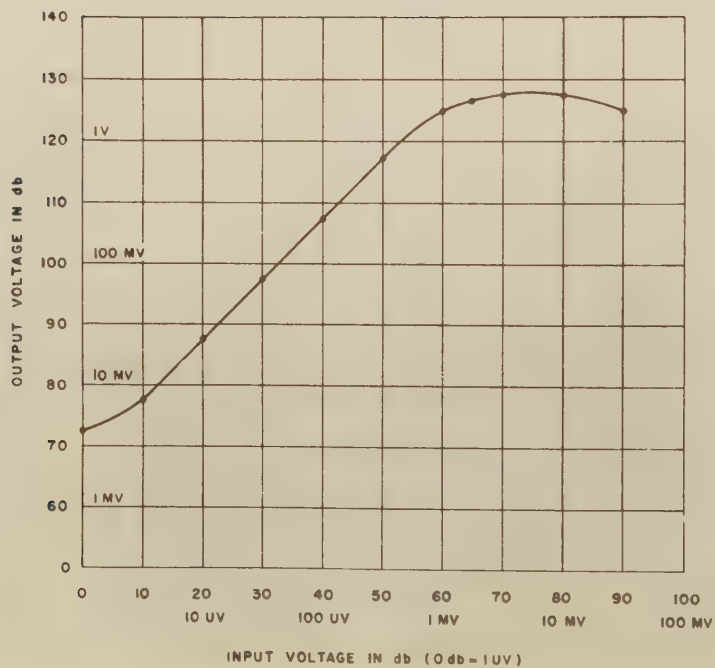


Fig. 9 - Gain characteristics of sub-module D.

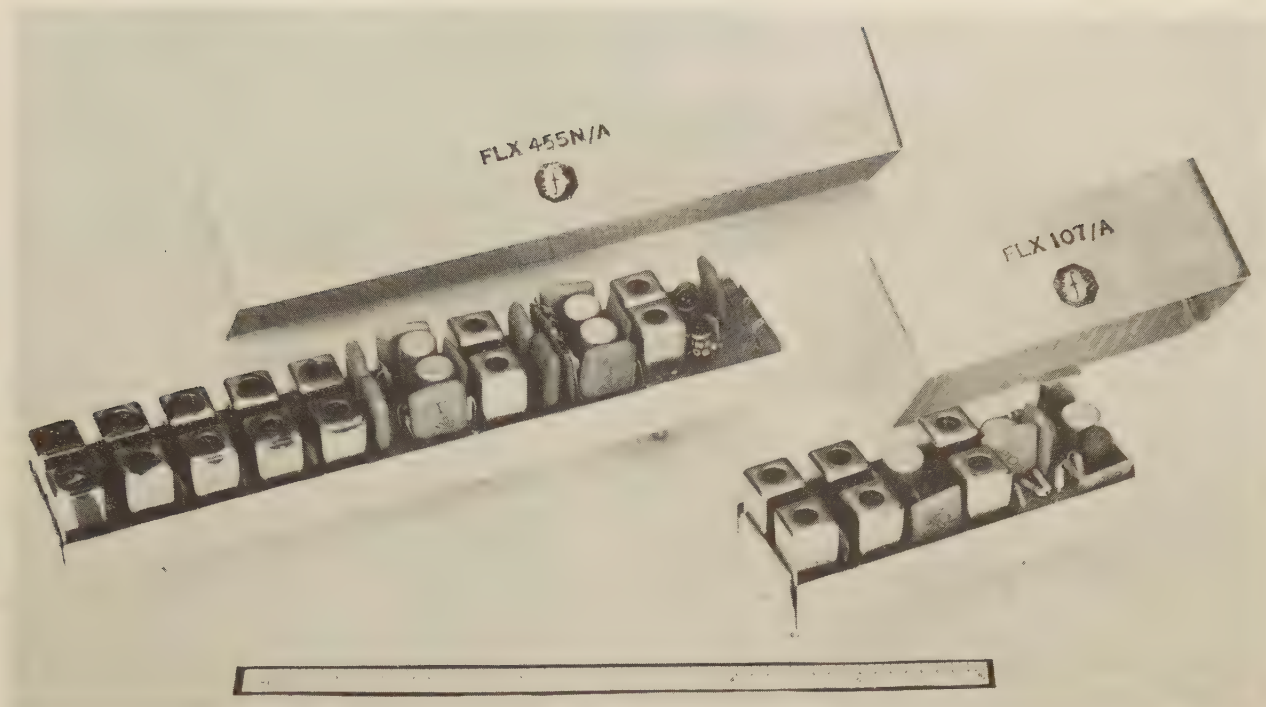


Fig. 10 - Open view of the two packages.

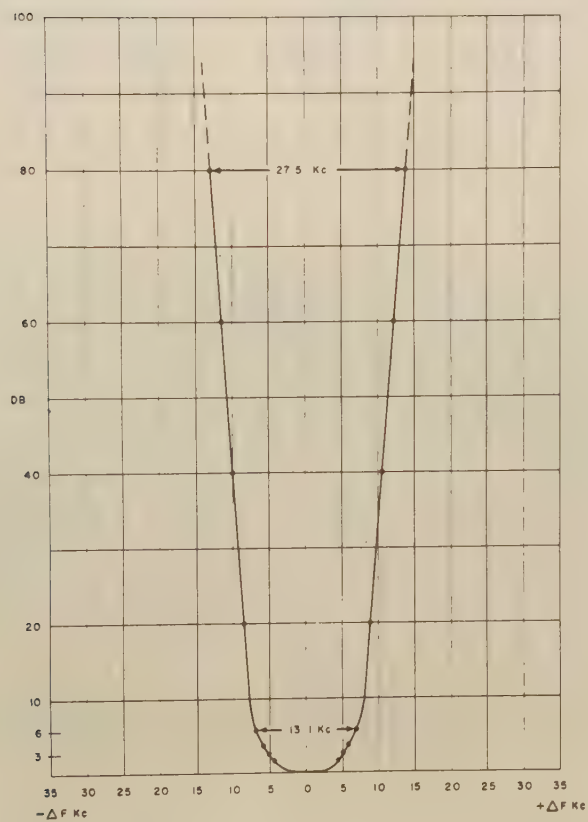


Fig. 11 - Over-all selectivity curve of 455 Kc unit.

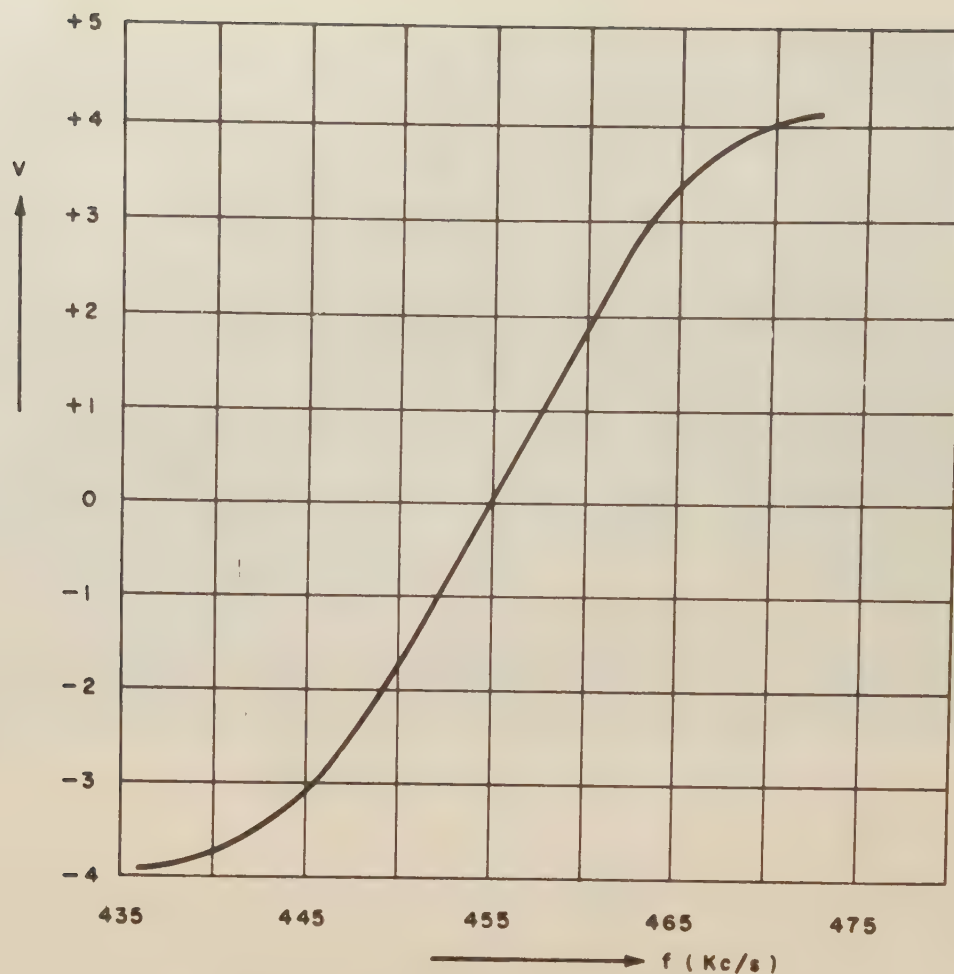


Fig. 12 - Discriminator curve.

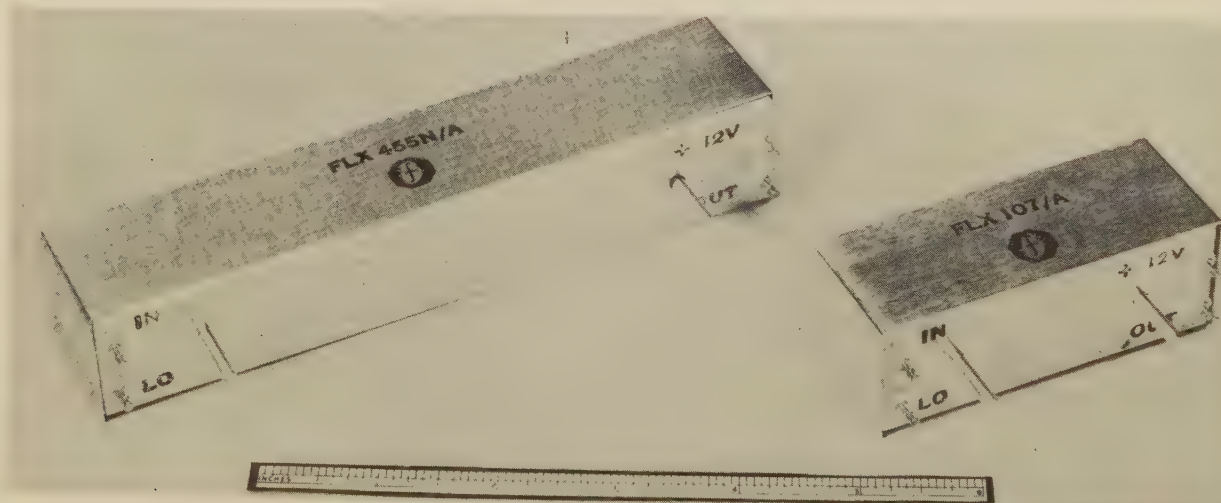


Fig. 13 - Closed view of the two packages.

A SELECTIVE RINGING DECODER FOR MOBILE RADIOTELEPHONE USE

James D. Malone
AC Spark Plug Div., GMC
Milwaukee, Wisconsin

A mobile radiotelephone must include a selective ringing decoder which signals the subscriber when his particular telephone is being called.

The decoder responds to the selective ringing signal transmitted by the base station, and if the call number transmitted is that for which the decoder is set, it rings a bell, or activates other audible or visible indicating devices.

The selective ringing signal is transmitted as two-tone sequential audio modulation of the radio-frequency carrier. A train of alternate 600 and 1500 cps tones is transmitted for each digit of the call number. Each frequency transition from 600 cps to 1500 cps, or vice versa, represents one unit in the digit. These transitions occur approximately 10 times per second.

There is a pause in the frequency transitions of approximately half a second between digits.

Figure 1 is a representation of the audio signal applied to a selective ringing decoder by the receiver of a mobile telephone when the three-digit number 3-5-2 is received. Call numbers are normally five-digit numbers, but for simplicity, a three-digit number has been shown.

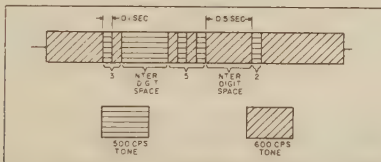


Fig. 1 - Audio signal: tones signaling 3-5-2.

The AC Spark Plug Division of General Motors Corporation has developed a selective ringing decoder for use with its 150 Mc automotive radiotelephone, and also with the 450 Mc airborne Skyphone designed by AC Spark Plug.

It was decided at the outset of the design program to make this decoder an electro-mechanical device, with transistorized control circuitry. Transistors, of course, are very well suited to this sort of application. The 12 volt and 28 volt dc electrical systems of automobiles and planes can furnish the supply voltage for the transistors directly. The small size of the transistors, their ruggedness, and their long life are assets, and the absence of a requirement for heater power is a distinct advantage, particularly in automotive service, where it is highly desirable to reduce battery drain to a minimum.

Although the decoding task can be accomplished entirely electronically, it was felt that the electro-mechanical approach yields a more economical device, since a considerable number of transistors and diodes would be required to perform the functions which are accomplished by the mechanical portion of the decoder.

Life testing of the mechanical parts of the decoder was begun early in the development program to insure that the design was adequate in this regard. As a result of this testing, several mechanical modifications which improved the reliability and extended the life of the decoder were made and tested before pilot production was begun.

Another basic decision made at the outset of the design program was that the decoder would be an integral part of the main receiver-transmitter package. The alternatives to this are either incorporating the decoder in the control head, or building it as a separate unit. Putting the decoder in the control head is unattractive because it makes the control head bulky and large. Building the decoder as a separate unit makes the radiotelephone installation more complex and costly. An extra wrap-around or housing has to be supplied for the decoder, this unit has to be mounted separately, and additional cables and plugs, with their extra cost, inconvenience, and possibilities for failure, are required.

For these reasons, the decoder was designed to be installed within the receiver-transmitter package.

This decision imposes certain requirements on the decoder. It must be compact but serviceable. It must be easily removeable, but it must be possible to change the call number for which the decoder is set without removing it, and without special tools. Most important, the decoder must be able to survive and function in the environment found within the receiver-transmitter package. The most severe aspect of this environment is the wide range of ambient temperatures in which the decoder must operate, and in particular, the high temperatures which may be reached.

This is particularly critical because the necessity for low cost dictates the use of germanium rather than silicon transistors, and in most cases, germanium rather than silicon diodes.

The AC Spark Plug decoder has been designed to operate in ambient temperatures from -30°C to $+85^{\circ}\text{C}$. To make the use of germanium devices feasible at high ambient temperatures, circuit

impedances have been kept low, so that the increased leakage currents which exist at high temperatures have a minimum effect on circuit performance.

The circuitry has been designed to be relatively insensitive to the gain of the transistors, and a substantial margin of base drive has been employed.

Although the transistors used are not of an expensive variety, the minimum permissible gain at low temperature, and the maximum permissible I_{CO} at high temperature have been specified.

Where capacitors with values above one microfarad are used for timing or coupling, solid tantalum capacitors have been employed, because of their small size and excellent temperature stability.

The decoder must be able to function properly over a wide range of battery voltages. The 12 volt version of this decoder will operate with battery voltages from 9.5 to 16 vdc, and the 28 volt version has a corresponding wide voltage tolerance.

The decoder should also perform satisfactorily over a range of tone transition rates. This decoder has been designed to operate with tone transition rates from 6.5 to 14 transitions per second.

To meet the future needs of the expanding mobile radio service, which now includes airborne as well as automotive telephones, the decoder must have a high code capacity, so that different telephone numbers can be assigned to a large number of vehicles and planes. The decoder described here will respond to any preselected call number chosen out of more than 51,000 available five-digit call numbers.

The actual decoding of an incoming call is done by an assembly consisting primarily of a code wheel, a stepping actuator, and a decoding actuator. Figure 2 is a simplified representation of this assembly.

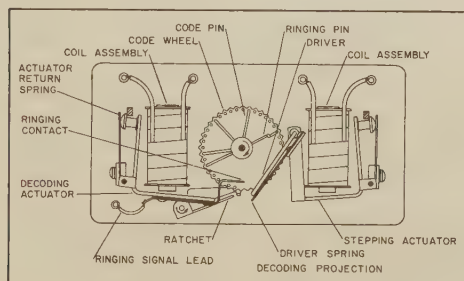


Fig. 2 - Mechanical assembly.

The assembly is shown in the zero, or starting position. The ratchet and code wheel are spring loaded, with the springs applying torque

in the directions shown by the arrows. Further clockwise rotation of the code wheel is prevented by a stop, which is beneath the wheel, and is not shown in Figure 2.

The first four code pins are L-shaped wire pins. The long end of the L is inserted in a groove in the wheel hub, and the short end of the L projects down through one of the holes around the periphery of the wheel, and extends a short distance below the bottom surface of the wheel.

The fifth code pin, or ringing pin, is somewhat similar, but has a bent loop which projects upward, and engages the ringing contact upon receipt of the correct call number.

The call number for which the decoder is set is established by the location of the code pins and the ringing pin around the periphery of the wheel. Their position can be easily and rapidly changed.

When the series of tone transitions representing a digit is received by the decoder, a voltage pulse is applied to the decoding actuator coil. This pulse begins at the first tone transition, and lasts until no transitions have occurred for about 200 milliseconds.

The application of this voltage pulse to the decoding actuator causes the decoding actuator to pivot counterclockwise against the force of the actuator return spring. The counterclockwise rotation of the decoding actuator allows the ratchet to move in, and engage the teeth of the code wheel.

The stepping actuator coil also is energized by the series of tone transitions. Each time a tone transition occurs, a voltage pulse about 40 milliseconds in duration is applied to the coil.

With each pulse, the stepping actuator is pivoted clockwise, and then returned by the actuator return spring. Each time the stepping actuator is pulsed, the driver, which is a U-shaped link, engages a tooth on the code wheel, and rotates the wheel counterclockwise one tooth. The ratchet prevents the wheel from falling back between pulses, since the decoding actuator remains energized until after the entire digit has been received.

Thus we see that the code wheel is rotated one tooth for each unit in the digit received. At the end of the digit, when there is a half second pause in the incoming tone transitions, the decoding actuator coil is de-energized. Unless the received digit is the correct first digit of the call number for which the decoder is set, the decoding actuator, in returning to its de-energized position, disengages the ratchet from the teeth of the code wheel, and the code wheel returns to its initial position.

However, if the received digit is the correct first digit of the call number, the first

code pin is carried around by the rotation of the wheel to a position in the path of the decoding projection on the decoding actuator. At the end of the digit, when the decoding actuator attempts to return to its original position, the portion of the code pin that sticks out from the bottom surface of the wheel catches the decoding projection. This stops the return travel of the decoding actuator before it disengages the ratchet from the wheel, so that the code wheel, having registered a correct digit, holds its position during the interdigit period.

When the second digit arrives, the actuators are again activated, and the code wheel is stepped on around, bringing the second code pin into the proper "register digit" position. The process is repeated for each of the five digits of the call number.

If any of the five digits is incorrect, the wheel falls back to its initial position at the end of that digit.

However, if all digits are correct, when the decoding actuator is de-energized at the conclusion of the fifth digit, the insulated ringing contact is caught by the wire loop projecting upward from the ringing pin. This grounds the ringing signal lead through the code wheel, ringing the bell of the radiotelephone.

Not shown in Figure 2 is a mechanical feature which prevents the stepping actuator from rotating a code pin more than one tooth past the "register digit" position without stopping at that position. This is accomplished by a lock-out lever carried on the decoding actuator. If a pin in the code wheel is rotated past this position without pausing to wait for the decoding actuator to be released, the lock-out lever is moved by the projection of the code pin beneath the wheel in such a way that it disengages the driver from the teeth on the wheel. At the conclusion of the digit, the wheel will then return to its starting position.

This feature is required to prevent the possibility of an incorrect digit bringing a code pin into the "register digit" position. For example, without this feature, an incoming 7 would be registered by the second code pin of a decoder whose first two code pins were set for 4-3, 5-2, or other combinations totaling 7. There would then be the possibility of the decoder responding incorrectly to call numbers other than the one for which it is set.

The manner in which the mechanical assembly recognizes a correct call number has been described. To perform this function, the decoding actuator coil must receive a voltage pulse which begins with the first tone transition, and lasts until the tone transitions have paused for about 200 milliseconds, during an inter-digit space. The stepping actuator coil must receive a 40 millisecond voltage pulse at each tone transition. The transistorized circuitry which pro-

vides the necessary pulses will be described next. Figure 3 is a block diagram of this circuitry.

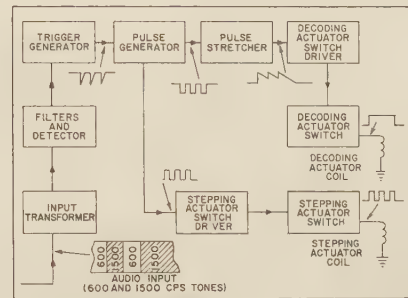


Fig. 3 - Block diagram.

The two-tone audio signal obtained by demodulation of the radio-frequency carrier is applied to the decoder through a transformer which matches the input impedance of the decoder to the output impedance of the circuit which supplies the signal. The primary of this transformer is normally connected in the plate circuit of a tube, although other arrangements may of course be used, if a transformer with proper impedances is chosen.

The audio signal from the input transformer is applied to simple series-resonant filters which separate the 600 and 1500 cps tones and direct them into different paths, while attenuating audio signals at other frequencies.

Tones which pass through the filters are applied to half-wave detectors, connected in such a way that their outputs subtract from each other, thus forming a composite Detector which has an output with a polarity which depends on whether the 600 cps or the 1500 cps content of the audio signal is stronger.

The output of the Detector controls the Trigger Generator. The Trigger Generator is a bistable circuit which develops a short negative output pulse whenever it switches from one stable state to the other.

The output of the Detector causes the Trigger Generator to assume one of its stable states when the 600 cps content of the audio input signal to the decoder is dominant, and to assume its other stable state when the 1500 cps content of the input signal is dominant. Because these states are stable, if the audio input signal is removed, the Trigger Generator remains in whichever state it happens to be in at the time. This "latching" action prevents the production of spurious trigger pulses caused by fading or interruption of the input signal.

The negative pulses developed by the Trigger Generator each time the audio tone frequency shifts from 600 cps to 1500 cps, or vice versa, trigger the Pulse Generator.

The Pulse Generator is a monostable, or "one-shot", multivibrator. Each time it is triggered, it develops both positive and negative output pulses, approximately 40 milliseconds in duration.

The positive output from the Pulse Generator is applied to the Stepping Actuator Switch Driver. The Switch Driver controls the Stepping Actuator Switch, producing a voltage pulse at the Stepping Actuator coil each time there is a pulse from the Pulse Generator.

The negative output from the Pulse Generator goes through a Pulse Stretcher to the Decoding Actuator Switch Driver, which controls the Decoding Actuator Switch. The Pulse Stretcher causes the voltage pulse produced at the Decoding Actuator coil to last at least 200 milliseconds after the latest pulse from the Pulse Generator.

In considering the operation of the circuit in more detail, it is helpful to examine various segments of the circuit separately.

Figure 4 shows the input transformer, the tone filters, and the Detector.

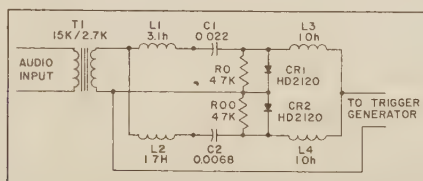


Fig. 4 - Transformer, filters, & detectors.

T1 is the input transformer. The transformer shown here, designed with a 15K to 2.7K impedance ratio, is used in the plate circuit of one half of a 12 AU7.

L1 and C1 form a series-resonant circuit at 600 cps; L2 and C2 are resonant at 1500 cps. These are the filters which separate the tones.

The transistorized Trigger Generator, which is controlled by the output of the Detector, has a low input impedance, and the Detector circuit is designed to perform properly with a very low-impedance load. CR1 and CR2 are the detector rectifiers, connected in shunt. L3 and L4 are smoothing chokes. These inductors accomplish smoothing of the rectified output current in a manner analogous to that in which a shunt capacitor smooths, or filters, the output voltage of a detector operating into a high-impedance load.

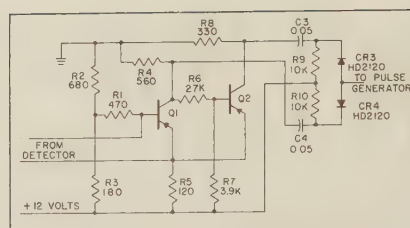


Fig. 5 - Trigger generator.

Q1 and Q2 form the Trigger Generator, which is an emitter-coupled, bistable circuit. It is designed to have considerable hysteresis with regard to its input signal; that is, the circuit shows a strong tendency to "latch" in whichever state it assumes.

In the presence of a 600 cps tone, the Detector causes the base of Q1 to go negative with respect to the emitter, turning on Q1, and cutting off Q2. If the 600 cps tone is removed, there is still enough base current drawn through R1 to keep Q1 in saturation.

However, in the presence of a 1500 cps tone, the Detector cancels base current through Q1, turning it off, with Q2 going into saturation.

C3, R9, and C4, R10 are differentiating networks which produce short trigger pulses from the square waves at the collectors of Q1 and Q2. CR3 and CR4 pass negative trigger pulses, but block positive pulses from reaching the output.

Figure 6 is a diagram of the Pulse Generator.

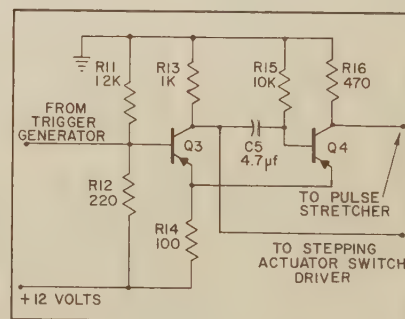


Fig. 6 - Pulse generator.

The Pulse Generator is a monostable, emitter-coupled multivibrator. Q4 is normally held in saturation by base current drawn through R15, and Q3 is cut off by the voltage maintained at its base by the voltage divider R11 and R12. When a negative pulse of sufficient amplitude reaches the base of Q3 from the Trigger Generator, the back-bias on Q3 is overcome, and Q3 begins to conduct. The multivibrator then fires, with Q4 going to cut-off, and Q3 into saturation. When C5 charges sufficiently through R15, Q4

again begins to conduct, and the circuit reverts to its original state. The duration of the pulse is primarily controlled by the time constant of C5 and R15.

Figure 7 is a diagram of the Stepping Actuator Switch Driver and the Stepping Actuator Switch.

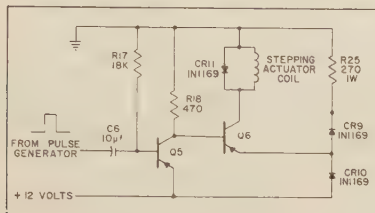


Fig. 7 - Stepping actuator switch driver, switch, and coil.

Q5 is normally held in saturation by base current drawn through R17. The voltage at the collector of Q5, and therefore at the base of Q6, is only about one-tenth of a volt below the supply voltage.

CR9 and CR10 are silicon diodes, which are connected in series with R25, to form a bias bleeder. The silicon diodes have forward conduction thresholds of about 0.6 volts. Hence the emitter of Q6 is held about 0.6 volts below the supply voltage, and Q6 is biased firmly into cut-off.

When a positive pulse from the Pulse Generator is coupled to the base of Q5 through C6, Q5 is cut-off, and its collector voltage falls until Q6 is turned on and driven into saturation by base current drawn through R18.

The dynamic impedance of CR10 is low, and the voltage drop across it is not much changed by the 300 milliamper pulse drawn through Q6, so that almost the entire supply voltage is applied to the Stepping Actuator Coil.

CR11 is a damping diode which eliminates the large negative voltage spike which would otherwise appear at the collector of Q6 at the end of the pulse, due to the inductance of the coil.

When a train of pulses is coupled through C6, dc restoration is accomplished by the base-emitter diode of Q5, which clamps the base voltage at supply potential.

Figure 8 is a diagram of the Pulse Stretcher, Decoding Actuator Switch Driver, and Decoding Actuator Switch.

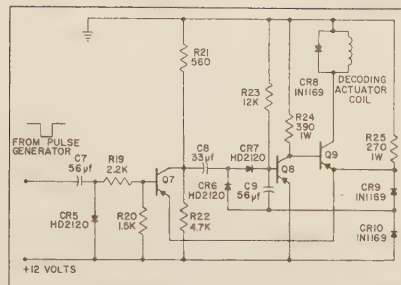


Fig. 8 - Pulse stretcher, decoding actuator switch driver, switch, and coil.

Q8 is normally held in saturation by base current through R23. Its collector voltage is within about one-tenth of a volt of the supply voltage, and Q9 is held firmly cut-off by the voltage drop of about 1.2 volts across CR9 and CR10.

The emitter of Q7 is also connected to the bias bleeder, and Q7 is held cut-off.

Negative pulses from the Pulse Generator are coupled to the base of Q7 through C7, turning Q7 on for the duration of each pulse. CR5 is a dc restorer required to keep C7 from charging during a train of pulses.

The positive pulses developed at the collector of Q7 drive the diode pump circuit comprised of C8, CR6, CR7, and C9, charging C9. The positive voltage at its base cuts off Q8. Q8 remains cut-off until the circuit stops pumping charge into C9, and the charge that C9 has acquired is removed through R23. The time constant $R_{23} C_9$ is long enough to ensure that Q8 will remain cut-off for 200 milliseconds after the Pulse Generator stops firing.

When Q8 is cut off, its collector voltage drops until Q9 is driven into saturation by base current through R24, applying a voltage pulse of slightly less than the supply voltage to the Decoding Actuator Coil. This pulse lasts until Q8 is again turned on.

CR8 is a damping diode for the Decoding Actuator Coil.

The functioning of the decoder has now been covered section by section.

Figure 9 is a diagram of the entire decoder.

Figure 10 is a photograph of the decoder.

The decoder is arranged in several decks held in a frame. Packaged this way, it can be installed in either the automotive radiotelephone, or the airborne Skyphone. Figure 11 shows the decks removed from the frame.

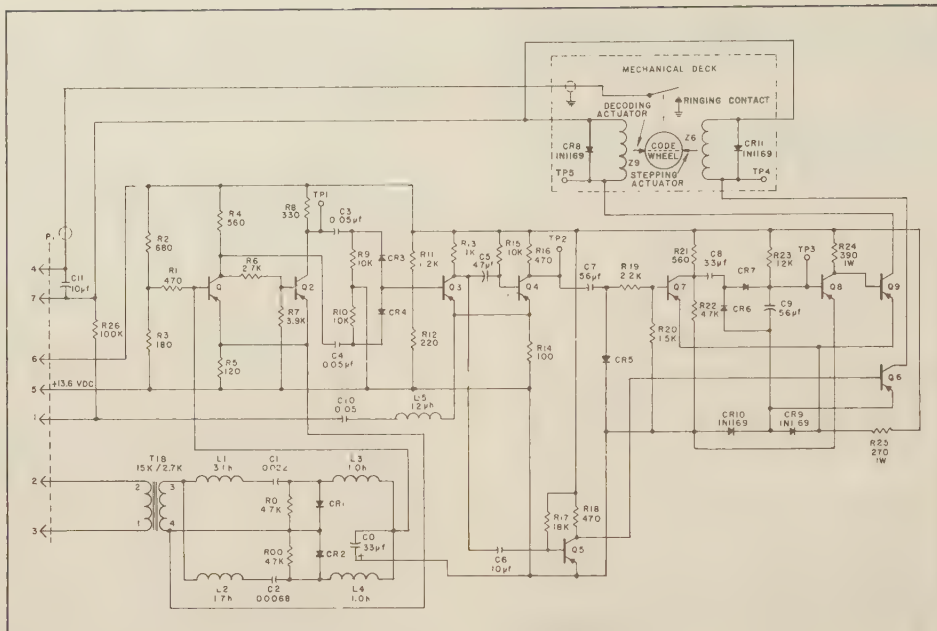


Fig. 9 - Schematic diagram.

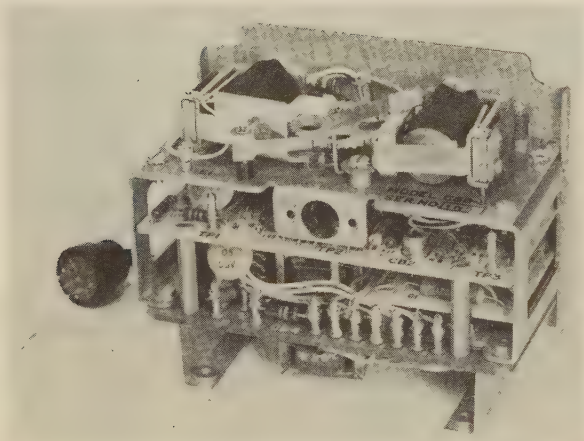


Fig. 10 - Decoder.

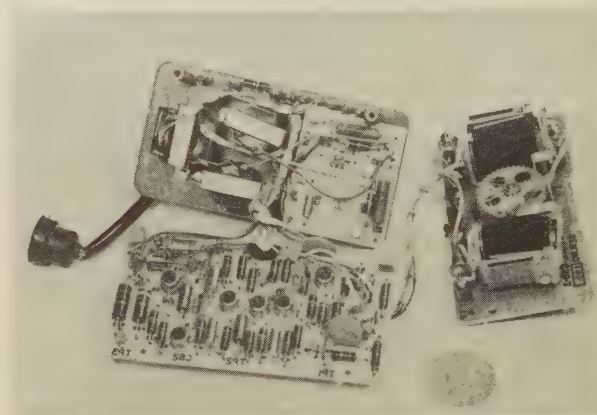


Fig. 11 - Decoder, disassembled.

A CENTRALIZED MOBILE TELEPHONE TEST PANEL

John P. Gill
New York Telephone Company
New York, N.Y.

Summary

A centralized method of testing Mobile, Test and Base Station Transmitters "Off the Air" has always been considered desirable. With the inauguration of 450 Mc. narrow band common carrier telephone service with its more stringent requirements, a centralized method of testing has become almost a necessity.

The Centralized Mobile Telephone Test Panel described herein can be used to evaluate the overall performance of a Mobile telephone system and can also be used as a tool to insure proper routine operation of a system. Provisions are made in the CMTTP for automatic sampling of each radio channel with statistical evaluation of ON-OFF frequency operation of mobile transmitters.

The present unit is arranged to monitor on the 450 Mc. and Personal Signaling (Bellboy) services only. However, the test panel can be readily adapted for the 40 and 150 Mc. channels as well.

- - - - -

Common Carrier Mobile Telephone Service began in the New York City Area in 1936 with the inauguration of Coastal Harbor Service. In 1939 our first Vehicular Mobile Telephone System was installed. There was no further expansion of these systems until after the war. By 1957 there was a total of fourteen dual channel systems in operation providing Highway, Urban and Maritime Service. A total of eighteen land based transmitters, fourteen test transmitters and fifty-one land receivers were in use to provide service to over nine thousand Coastal Harbor and over six hundred Vehicular Mobile Telephone Customers.

Figure 1 shows the geographical layout of the 40 and 150 Mc. wide band Highway, Urban and Maritime Systems. The land receivers are distributed throughout the Metropolitan Area. The base transmitters are located at the lower end of Manhattan Island - 32 Avenue of the Americas. The test transmitters are located at 108th Street. These test transmitters play an important part in testing out the proper functioning of the land based receivers for sensitivity and audio output and are also used by the radioman as a precise signal source in checking for zero discriminator and front end alignment. It is, therefore, important that the test transmitters are maintained well within frequency tolerance, radiating the proper power with proper modulation deviation.

These wide band systems are being maintained by what might be called "standard procedures" without much difficulty. The frequency tolerance for the 150 Mc. system is 50 ppm. Test set tolerances are 25 ppm.

In the latter part of 1957 four 450 Mc. narrow band channels were added to the urban systems. These were QB, QF, QH, QL. The Land based Transmitters operate on approximately 454 Mc. The Mobile Transmitters operate on approximately 459 Mc. - a 5 Mc. separation.

Figure 2 shows the geographical layout of the 450 Mc. Narrow band Urban System. The receivers are located at Hoe Avenue in the Bronx, Jamaica, Long Island, the Empire State Building in Manhattan and Long Lines Building - 32 Avenue of the Americas in lower Manhattan. The Land Transmitters are located at 32 Avenue of the Americas with an output power of 100 watts into a 5.8 db gain antenna. The Test Transmitters are located at 108th Street and perform the same function as

on the lower frequency systems. Their importance in maintenance is greater, however, because of the tighter tolerances on the 450 Mc. band.

Figure 3 shows graphically the 150 Mc. wide band requirements of 50 ppm versus the 5 ppm frequency tolerance for the 450 Mc. narrow band system. Also shown on Figure 3 is the technical requirements of 1 ppm carrier frequency tolerance for Personal Signaling Service (Bellboy) on trial in lower Manhattan. The lower portion of Figure 3 illustrates the modulation deviation requirements for the 150, 450 and Personal Signaling Service (Bellboy).

When a mobile telephone system extends over several divisions or areas where several frequency-deviation meters are in use, it is important that the frequency-deviation meters and the radio equipment are adjusted and maintained well within tolerances. When a narrow band system is involved, this statement should be changed from Important to Imperative.

In order to keep the 450 Mc. systems working satisfactorily it appeared necessary to make daily checks of frequency and modulation deviation of the base and test transmitters. This required the dispatching of two radiomen to both the base and test transmitter sites. Mobile equipment was being called in for recheck whenever available. There was considerable opposition by the customer to this procedure. The frequency-modulation deviation test equipment was checked and recalibrated when necessary on a weekly rather than the usual six month interval.

There are other items other than frequency misadjustment or drift that can render a service noncommercial. These include, over or under modulation adjustments of the transmitters both base or mobile, distorted dialing tones, low transmitter power, improper operating Vogads, improper use of equipment by customers.

Whereas individual tests of the 450 Mc. units indicated proper operation, the system as a whole was not up to full

expectancy. It appeared that what was needed was a Centralized method of Monitoring, Measuring and Evaluating the 450 Mc. system on a Dynamic basis "Off the Air" while the equipment was in service.

A test panel was assembled for this purpose and is known as a Centralized Mobile Telephone Test Panel. This has been abbreviated to CMTTP.

The CMTTP uses standard unmodified four frequency receivers and four frequency transmitter-receiver crystal panels as basic monitoring units. The monitoring and measuring can be performed at a remote point. The test panel enables measurements of the three important parameters of a P.M. transmitter. These are:

- (a) Carrier Frequency
- (b) Power Output
- (c) Carrier Modulation Deviation

A Frequency Counter and WWV receiver is used as a reference standard. An automatic feature is provided which permits an evaluation of "ON or OFF" frequency operation of Mobile units. The panel is also equipped with an over-modulation alarm.

Figure 4 is a photograph of the base station monitoring receiver and its associated four frequency transmitter-receiver crystal panel. The four frequency crystal panel is normally used in mobile stations. In this application the normal mobile frequency transmitting crystals have been replaced by base station frequency crystals and are used as a test signal source in setting the base station monitoring receiver to a zero discriminator reading. The plugs and cords are those normally used with this equipment for regular mobile service. These plugs are inserted into appropriate sockets on the CMTTP receiver subpanel to obtain power and to complete termination of the receiver circuits. The receiver has pin jacks for monitoring the discriminator and first limiter for normal servicing. These are the "take off" points for all measurements.

An identical receiver and four frequency transmitter-receiver crystal panel

is used to monitor the Mobile Station Frequencies. In this application the normal mobile station receiver crystals have been replaced by land base receiver crystals to enable monitoring on the mobile frequencies. The regular mobile transmitter crystals are retained as a test signal source in setting the mobile monitoring receiver to a zero discriminator reading.

Figure 5 is the basic block diagram of the CMTTP. The method used is to monitor the discriminator of the F.M. detector to determine "ON or OFF" frequency operation of the F.M. carrier. A zero center 50-0-50 microampere meter with a calibrating multiplier resistor is used as an indicator. The meter scale reads -13 KC "0" +13 KC. A second meter (50 microamperes) marked "carrier level" is connected to the first limiter through a multiplier resistor. The meter reads 5 volts full scale and gives a comparative reading of carrier power based either on previous readings or as a comparison to readings from other transmitters operating in the same band and from the same location. The third meter (100 microamperes) which is arranged as an A.C.V. T.V.M. is calibrated to read modulation deviation. The meter reads 15 KC Full Scale. It should be noted that the "take off" point for the modulation deviation readings is before the de-emphasis network, therefore, the Modulation Deviation Meter will read true modulation deviation of the carrier (sine wave). The over modulation alarm can be set to trigger and release at any setting desired.

To check the Carrier Frequency Deviation Meter "live zero" for correct frequency, the test signal oscillator for the particular channel under test is activated (this would be one of the transmitter crystals in the four frequency panel). If the QB base station frequency of 454.55 Mc. is to be checked, the QB test crystal is activated. This will give a reading of 12626.388 KC on the frequency counter. A tolerance of ± 12 cycles is permitted. The 36th Harmonic (454.55 Mc.) of the test crystal frequency is selected by the receiver through capacitive coupling. The Carrier

Frequency Deviation Meter "live zero" is noted for a reading tolerance of ± 250 cycles. Corrections are made if required by means of the crystal trimmers on the four frequency panel or "front end" crystal of the receiver. The 524D Frequency Counter is checked against the Bureau of Standards by means of a WWV Receiver.

Figure 6 illustrates the method used to calibrate the Carrier Frequency Deviation (Discriminator) and Modulation Deviation Meters. In aligning the monitoring receivers the following procedure is used:

- A. The D.C. Calibrate Rheostat is adjusted so that 3 volts DC between ground and the discriminator lead will produce full scale deflection $\pm$ with $\pm$ reversal of the 3 volt D.C. test battery.
- B. With the oscillator set up as in the illustration, adjust the primary and secondary tuning of the discriminator transformer so as to obtain equal D.C. displacement $\pm$ on the Carrier Frequency Meter with equal ± 10 KC deviation from 290 KC.
- C. Repeat step B for the second receiver and adjust the Discriminator Calibrate resistor to obtain the same reading on the Carrier Frequency Deviation Meter for the same frequency displacement for each receiver.
- D. Calibrate the Meter Scale in one KC steps.

The Carrier Modulation Deviation Meter is calibrated by first noting the amount of positive and negative D.C. displacement of the 304H D.C. Scope when making the Carrier Frequency Deviation Meter Calibration (± 10 KC). The 200CD oscillator is then shifted to the Discriminator Jack and adjusted for 1 KC output. The output of the 200 CD is then raised until the peaks of the sine wave just touch the calibrate marks on the 304H Scope noted for a ± 10 KC carrier displacement. The A.C. Calibrate Potentiometer is then adjusted to obtain a

reading of ± 10 KC modulation deviation on the Modulation Deviation Meter. Calibrate the meter in 1 KC steps.

Test Signal Levels

It is important to note that the Modulation Deviation Meter on the CMTTP is calibrated to read on Sine Wave Modulation. This follows standard practice when a meter movement is used as an indicating device. In Common Carrier practice, sine wave 1000 cycle tone is always used for test purposes. Likewise the 600 and 1500 cycle dialing tones are of sine wave output. The modulated output from the Land Based and Test transmitters are set for definite values which are below limiting. In the 450 Mc. Service, 1000 cycle sine wave at zero level at the transmitting DPX outjack should produce 4.5 KC Modulation Deviation. 1500 cycle sine wave at +7 DBM at the transmitting DPX jack should produce ± 13 KC Modulation Deviation.

The Modulation Deviation Meter on the CMTTP and all other similar indicating devices can be used to set the maximum deviation limits of a transmitter provided the limiter in the transmitter is not driven so hard by the modulating signal as to cause so severe harmonic distortion that it cannot be cleared out by the post limiter filter. Some manufacturers specify adequate (1 volt) but caution against excessive (1.5 volts or more) as modulation testing levels in recognition of this problem.

Figure 7 is a graph of the discriminator D.C. output voltage versus Carrier displacement from normal 290 KC "zero". This graph is a plot of two receivers. In most cases the two plots coincide so that for all practical purposes the discriminator curves is linear and identical. The arrows either side of 290 KC indicate the frequency tolerance ± 5 ppm or ± 2.25 KC.

Figure 8 is a graph of the discriminator voltage on a positive excursion out to 15 KC and the equivalent R.M.S. voltage whose peak wave would produce a similar excursion. Since the positive and negative waves are identical, Figure 8 indicates the positive excursion only.

Figure 9 is an overall Block diagram of the CMTTP. The upper panel with its meters, loudspeaker and over-modulation alarm can be switched to either the Base or Mobile monitoring receiver. A particular channel is selected by operating the particular channel selector button. The Discriminator zero is checked by pressing the PUSH to CHECK button. The Base Test, or Mobile Station can now be checked on this particular channel by noting the readings on the various meters. The tolerance for Base and Test Transmitters are: Carrier Frequency Tolerance ± 2.25 KC, Carrier Level 4 volts minimum, Modulation Deviation 4.5 KC $\pm .5$ KC for standard level of 1000 cycles at the DPX Jack. These tolerances are indicated by green overlay markers on the indicating meters.

For Mobile Transmitters, experience indicates that normal voice modulation of a properly set transmitter produces peaks up to 5 KC modulation deviation on our particular modulation deviation meter.

The CMTTP is also equipped for automatic evaluation of ON or OFF frequency operation of mobile transmitters. The equipment is set up for these tests by depressing the two automatic buttons on the switching panel, and placing the Master Switch in the Mobile position. Each mobile channel will be monitored for 2 minutes with a repeat every 10 minutes. Mechanical counters will score all out of tolerance operations. A Codan relay mechanical counter will score every channel operation so that a percentage of ON or OFF frequency operation for a channel or all channels can be arrived at. The Personal Signalling Transmitters are checked by operating the Master Switch into the P.S.S. position. The test crystal frequency ± 1 ppm is checked with the frequency counter. A V.T.V.M. circuit is automatically inserted ahead of the Carrier Frequency Deviation Meter to increase its sensitivity. The meter then reads -500 "0" +500 C.P.S. The tolerance for the P.S.S. service is ± 150 C.P.S.

Figure 10 is a photograph of the Centralized Mobile Telephone Test Panel.

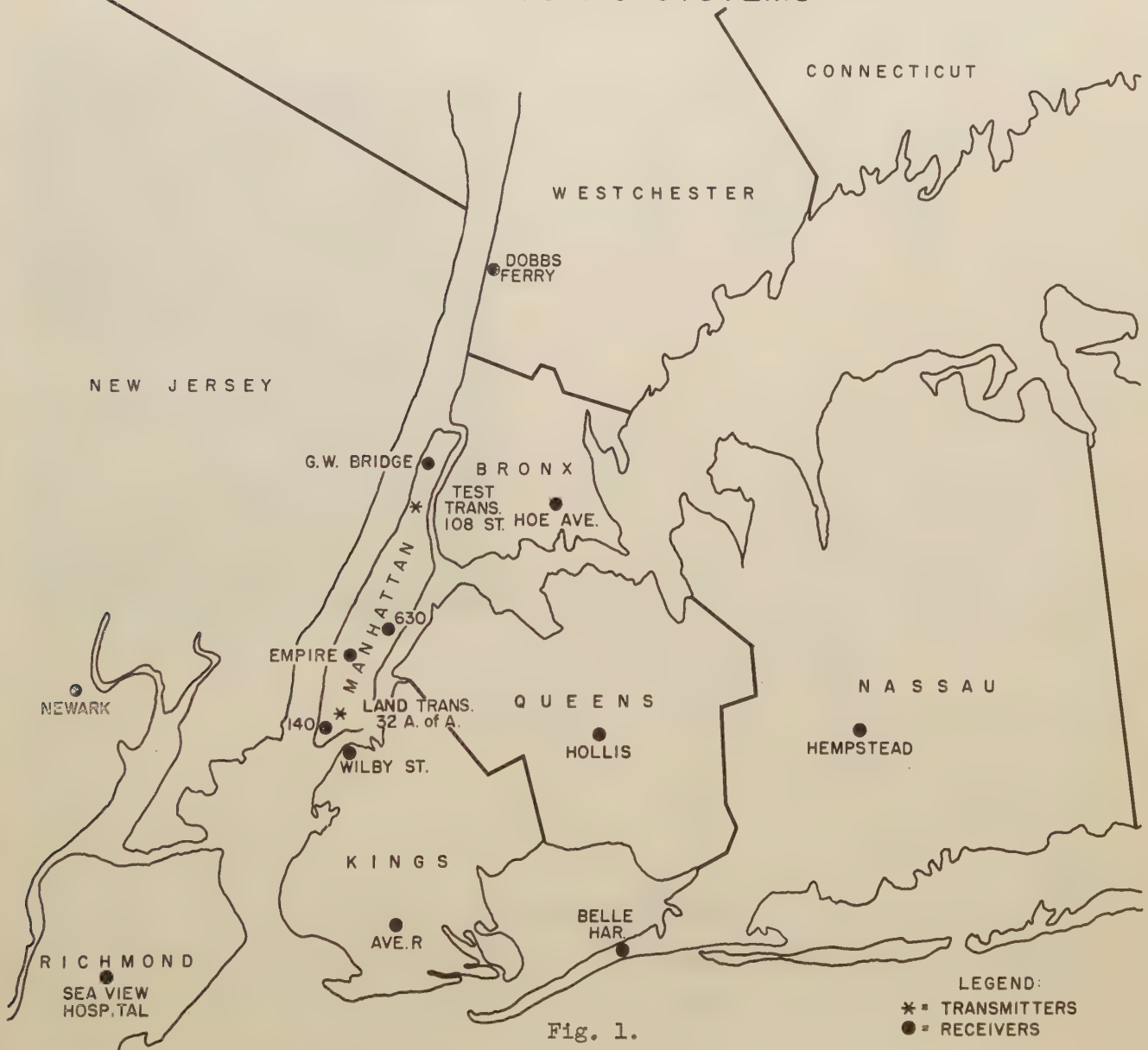
As presently designed and in operation at the Empire State Radio Terminal

the CMTTP enables a check of 200 mobile and 12 Base-Test transmitters.

The Centralized Mobile Telephone Test Panel has been found to be extremely useful not only as an engineering investigating tool but also as a labor saving, precise way of knowing just how a Mobile Telephone System is performing. The very simplicity of operation and interpretation of readings enables the CMTTP to be used by a radioman with a minimum of training.

We have found the dynamic test method made possible by the use of the Centralized Mobile Telephone Test Panel to be indispensable in the overall maintenance of our 450 Mc. and Bellboy services.

TRANSMITTER AND RECEIVER LOCATIONS 40 AND 150 MC SYSTEMS



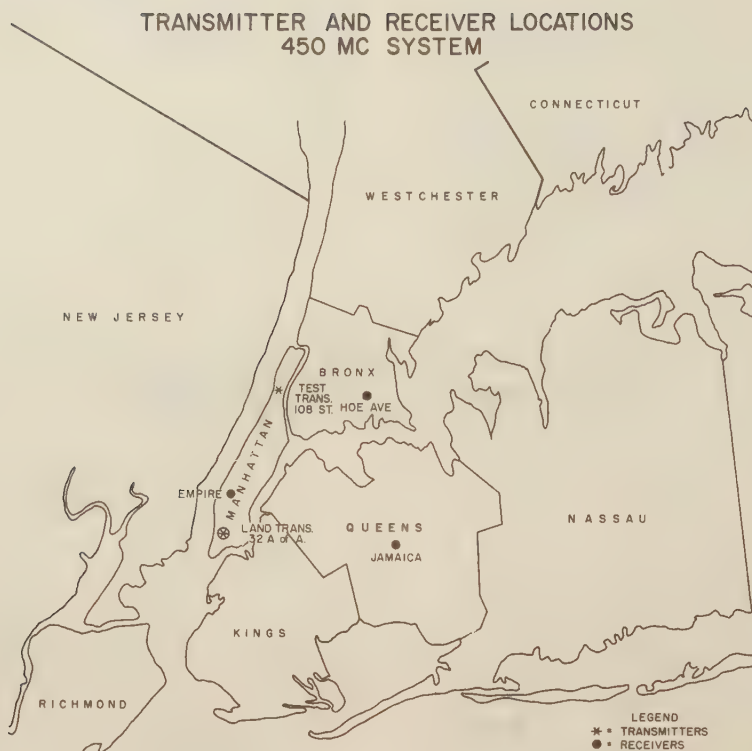


Fig. 2.

150 M. C. WIDE BAND REQUIREMENTS VERSUS 450 M. C. NARROW BAND REQUIREMENTS

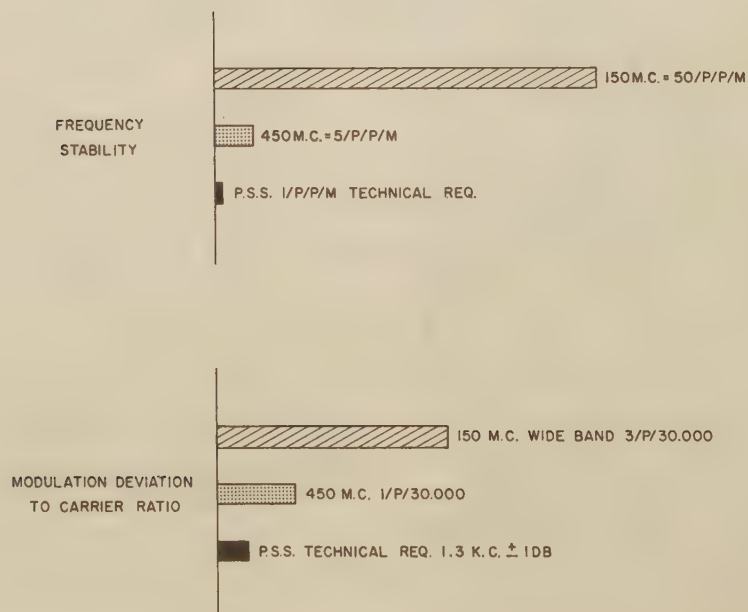
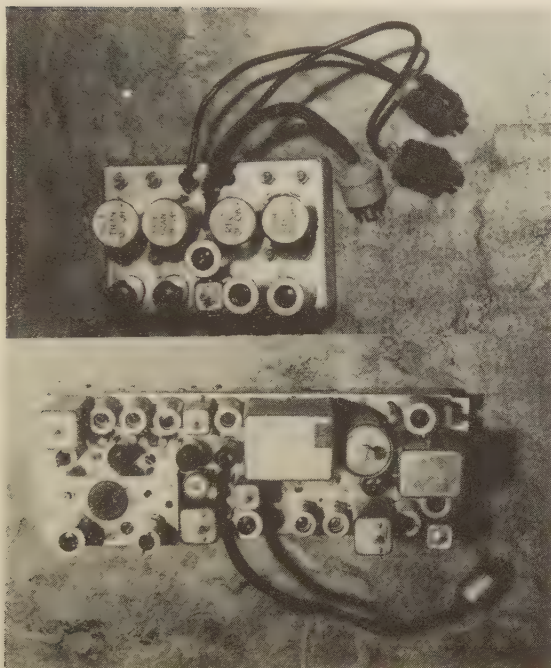


Fig. 3.

FOUR FREQUENCY
PANEL



RECEIVER

Fig. 4.

BASIC CIRCUIT CMTTP

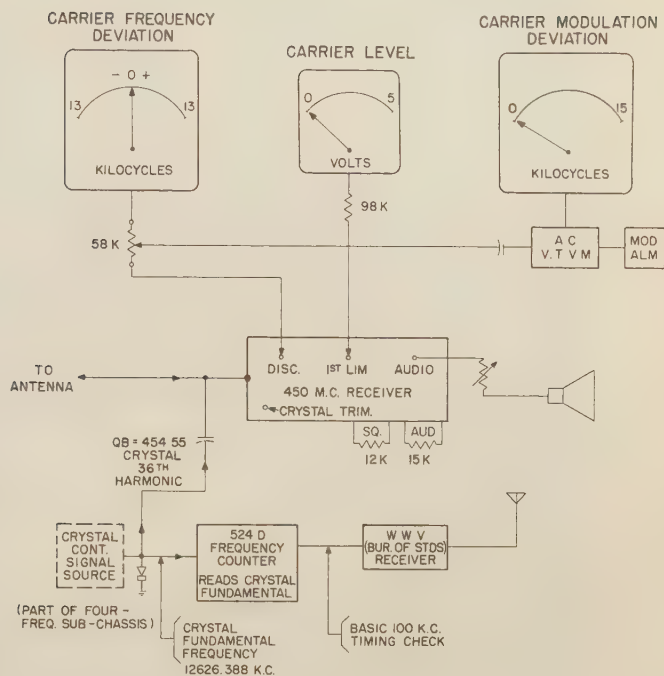


Fig. 5.

CALIBRATION OF DISCRIMINATOR & MODULATION METERS

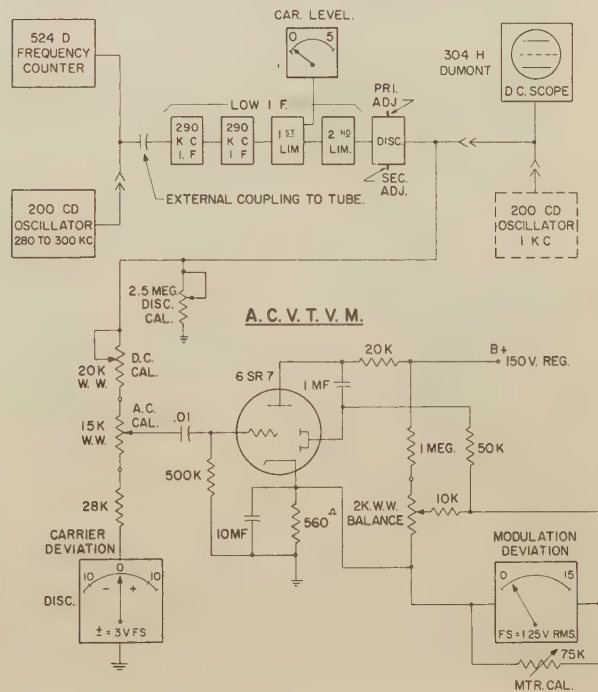
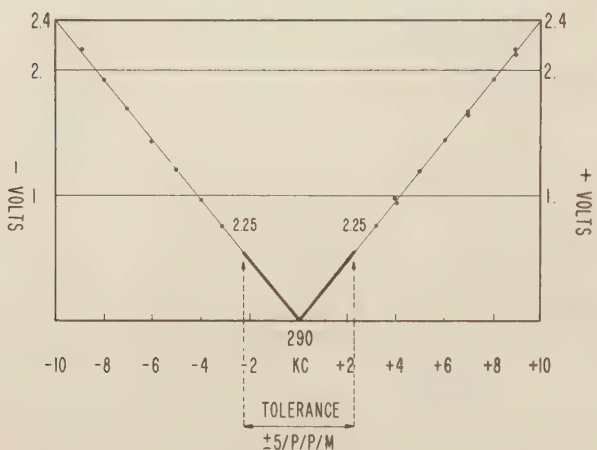


Fig. 6.

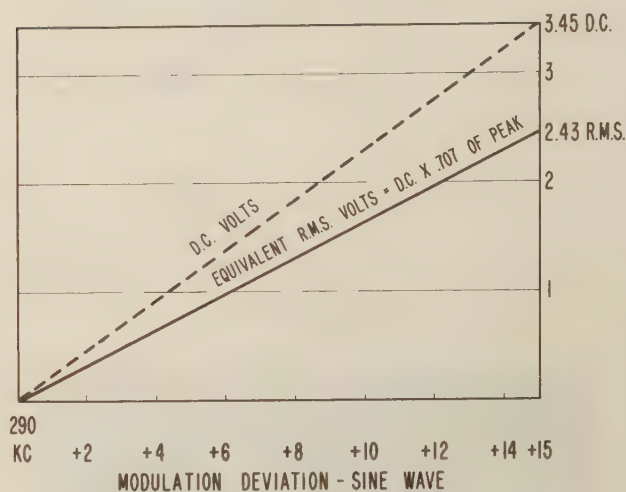
D.C. CALIBRATION-DISCRIMINATOR

IDEAL = STRAIGHT LINE. DOTS = PLOTS OF TWO RECEIVERS



D.C. TO R.M.S. CONVERSION

TO PRODUCE EQUIVALENT PEAK POSITIVE & NEGATIVE MODULATION DEVIATION OF CARRIER



OPERATIONAL BLOCK DIAGRAM

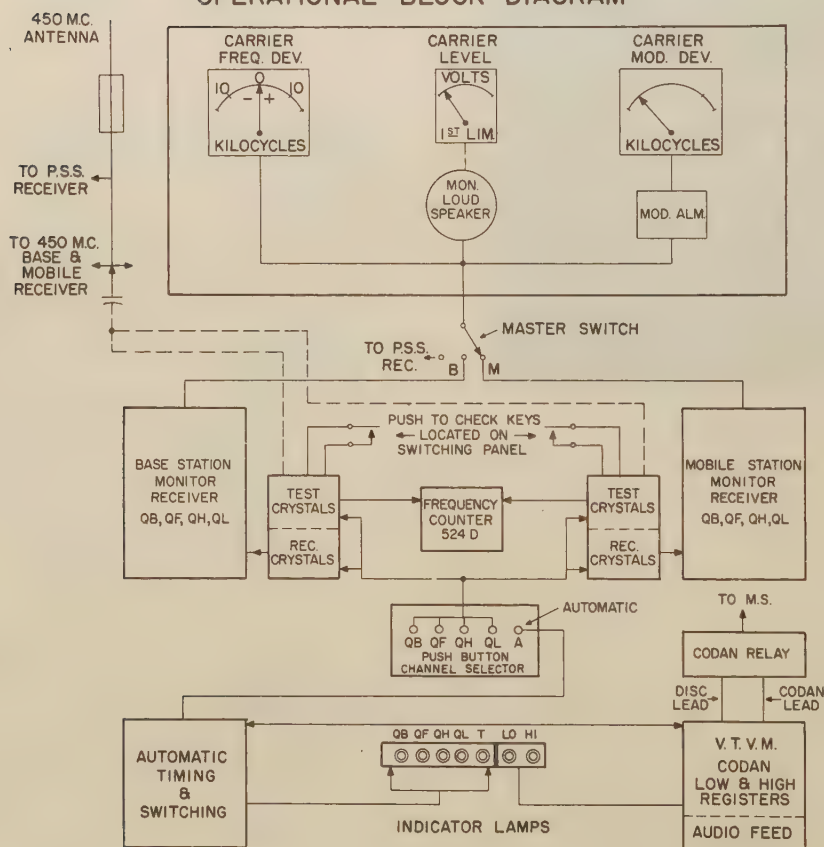


Fig. 9.

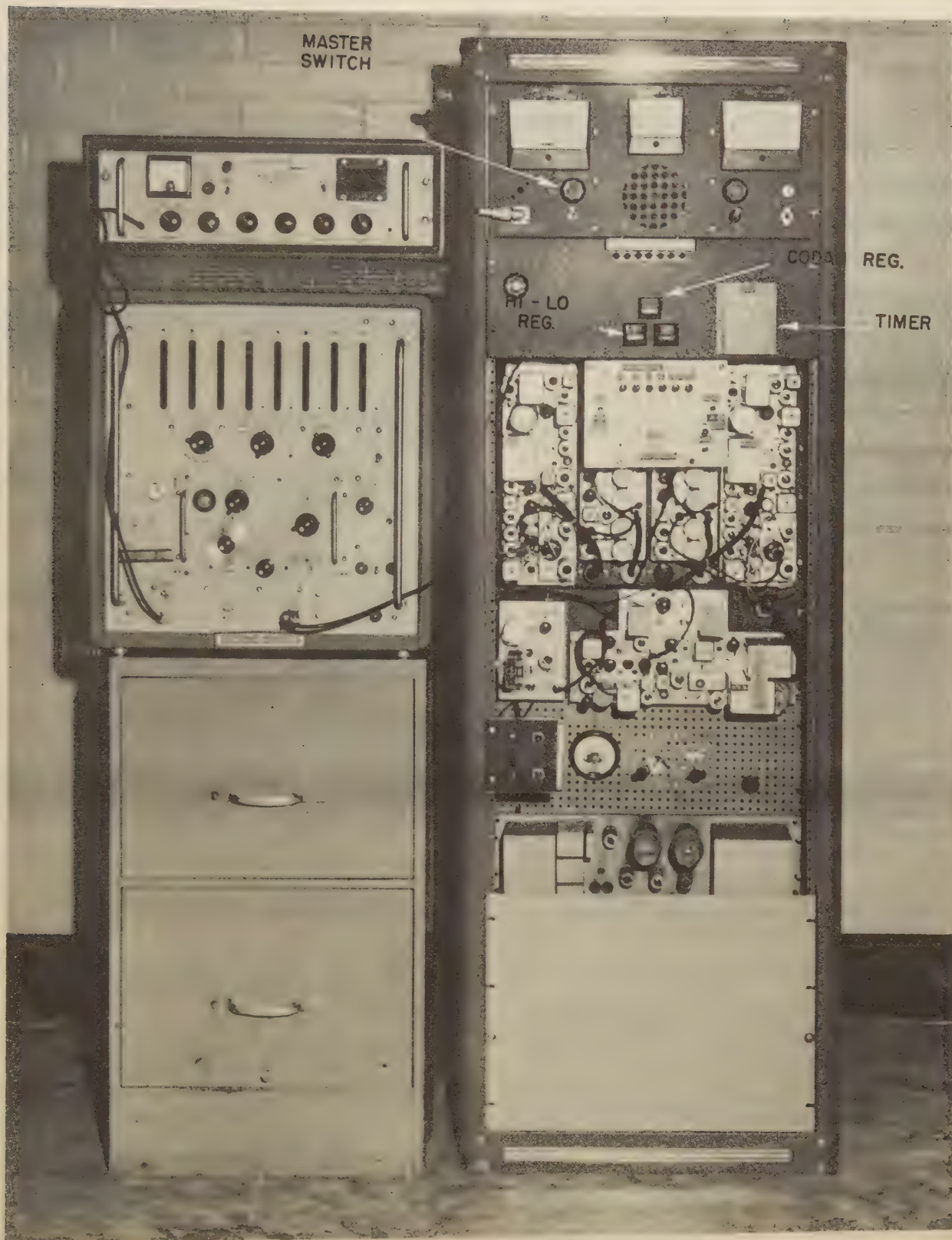


Fig. 10.

CONTROL CONSOLES - THE VHF INTEGRATORS

Hugh H. Davids
General Electric Company
Lynchburg, Va.

Summary

Control circuitry integrate pieces of communication equipment into VHF communication systems. The control functions for simpler systems are adequately provided by standard remote control units, using options to provide for a variety of needs.

More complex systems require special control circuitry and control consoles whose design is part of the overall system design. A duplex backbone system such as used on cross-state turnpikes is typical of such complex systems. Party line vs. multi-channel design of such systems is contrasted and use of various devices such as receiver voting discussed.

Console design is illustrated by discussing features of the Massachusetts Turnpike Control Console. Range of control design is indicated by mention of two-way mobile telephone requirements and the potential field of remote control from portable control consoles, such as remote control of a switching locomotive.

Introduction

Radar has become a household word, and as a result, we in Engineering immediately associate the term integrating circuit with pulse shaping techniques. There is, however, a different sense in which we can use the term integrating circuits. We can apply it to those circuits that control individual pieces of communication equipment and integrate them into an operational communications system.

VHF Systems Control Requirements

In some services, such as the Industrial Radio Service, where you have simplex single-frequency assignments, the control circuitry is rudimentary and can even be a part of the basic station package. For example, a system may consist of a locally controlled base station and a number of mobile units.

When we add to this simple system remote control of the base station, the control circuitry becomes a basic factor in the systems design, as you now have a remote control unit at the control point and a relay panel at the base station.

(Figure 1) The addition of more than one base station to our simple simplex system increases the complexity of control.

In the Public Safety services with duplex frequency assignments there is often the need of both car-to-base and car to our communications using the base station for a repeater in the latter case. In this case, the control circuits must provide the dispatcher with access to and supervision of the base station. This again adds complexity to the control circuitry.

Remote Control Unit

(Figure 2) Such systems can normally be remotely controlled over a single wire line pair by a standard remote control unit. (Figure 3) The basic unit provides for connection of the microphone, keying, audio level, remote squelch, modulation level indication and loudspeaker. To this basic unit, options can be added such as channel selection, tone alert oscillator, line level meter and compression amplifier. Switch kits for frequency selection, etc. provide for applying control voltages of nominal -105V, +105V, -45V, +45V and, of course, 0V DC to the control pair.

Where the remote switching functions exceed four, or where use of a radio control link precludes the use of DC control voltages, pulse tone control can be added.

Similarly, tone signalling or tone selection of mobile units, either by combination of tone pulses or by dialled tone pulses, can be readily added.

A system, such as a zoned taxi system (Figure 4) using several pairs of frequencies, individual zone dispatchers, and a master dispatch control, is typical of a system in which control requirements begin to exceed the capabilities of off-the-shelf equipment.

As we increase the number of stations in a system or the number of frequencies used, we greatly increase the complexity of the control equipment necessary to integrate the system.

Duplex Backbone Systems

A duplex backbone system as used on highway systems, railroads, pipe lines and other utilities probably calls for the most complex control circuitry (Figure 5). By backbone system, we mean a series of VHF base stations operating on the same frequencies and connected to a central control point by a point-to-point communication media.

The control needs of such a system cannot be met by assembling a standard remote control unit and a number of auxiliary control units together. No matter how well each was designed from the point of human engineering, the resultant combination would be confusing and tiring to use.

The control console for such systems has to be custom designed to meet the specific system needs and the operational requirements. In fact, the control requirements should be factored in to overall system planning since they may affect other areas than the control console.

Party Line Vs. Multi-channel Systems

For example, where the communications needs of the system can be met by giving the control points the ability to talk out to any or all the mobile units from all the base stations at once, a party-line connection over a single wire line or microwave channel is adequate.

This provides a simple system but it has limited flexibility. Some of the problems can be met by adding auxiliary equipment. For instance, there is the problem of cross-over area in which the signals received by a mobile receiver from two base stations are within 6 db of each other in signal strength and as a result the received signal is garbled. By using stable oscillators with a long term stability of one part per 10^6 and phase equalization of the tele-

phone lines feeding the stations, the area of unintelligibility can be minimized.

If a multi-channel microwave equipment is provided for the backbone, so that each station has its own channel connecting it to the control console you have a far more flexible system.

During periods of heavy traffic, it can be readily sectionalized to allow the load to be divided between several dispatchers. Two base stations may be patched together to permit two mobiles remotely located to each other to communicate, while other base stations are used to handle several other communications. A great variety of combinations can be made using simple switching operations at the console.

Special Control Circuitry

There are a number of devices that can be added to the basic communication control equipment to improve systems operation and for each system the benefits received must be weighed against the added complexity and cost.

Receiver Voting An example of this is receiver voting. In a backbone system, the signal from a single mobile transmitter may be picked up by the receivers in two or more base stations. Listening to the combination of outputs results in poor intelligibility due to phase differences and noise contributed by poor signals. The simplest way to select one receiver to which to listen would be to provide Carrier Operated Relays at each receiver, and have the first COR to close initiate a lock out signal for other receivers. This has the disadvantage that in a free-for-all race the poorest signal may well happen to lock out the better signals.

A superior way to make this selection is by adding a Voting Delay Panel at each receiver. The circuit for this is shown in (Figure 6). R3 controls the negative potential to which C2 charges on the negative half cycles when the COR is open. The negative voltage on the grid of tube VIA determines the discharge rate on positive cycles when the COR is closed.

The curves in Figure 7 explain the operation of the circuit. As shown, a stronger signal reduces the delay and permits the voting contacts to close faster.

The voting contacts are used to initiate lockout of receivers with weaker signals, since

normally the strongest signal is the most intelligible signal.

In multi-channel microwave backbone systems where each receiver has its own voice channel to the console, the voting signal can be an E&M signal. The selection of receiver is done at a voting lock out panel at the console, and can be readily done by interlocking relays which disconnect the incoming receiver lines from the console audio output circuits. In the case where two stations vote simultaneously, an arbitrary priority is built into the relay circuits; such as, the station nearest the control point having priority. The circuitry can be designed for operating the system in sections, with receiver lockout on a sectional basis, or even with lockout of just the two stations adjacent to the one selected, and the other receivers transferred to a second voting lockout panel.

Receiver voting can also be applied to a party line system using continuous tone signals for voting and lockout functions, necessitating a second channel connecting the stations to the control console. Here again, practical considerations demand that the lockout function be performed at a voting lockout panel at the console. In this case, the lockout panel initiates a lockout tone, and an individual lockout canceling tone for the selected station, and the actual lockout has to be performed at the base stations. This requires n incoming tones and $n+1$ outgoing tones for n stations. It can be readily seen that further sophistication of the lockout circuitry is much less practical than with a multi-channel system, since it would call for more tone signals and more tone equipment both at the control point and the remote stations.

The Voting Circuitry also provides for operation of "In use" indicators for the base station receivers. A feature for which provision would normally be made even if receiver voting was not needed.

Standby Switching When Public Safety or prevention of serious property loss requires certainty of continuity of operation, standby auxiliary primary power sources and radio equipment may be justified.

Automatic switching of the auxiliary power source at the base station is the most practical type of operation. However, whenever the aux-

iliary power source is operating, a signal should be transmitted back to the control console to light an indicator lamp showing this condition exists at this particular base station.

If the station fails to return to the normal power source in a reasonable length of time, the dispatcher will alert the service group to investigate the cause of outage.

After a need of standby RF equipment has been established, we still have to balance control circuitry cost against need. The simplest standby system is one without automatic feedback.

In this case the dispatcher tries to contact a mobile unit through a given base station, and if he does not get an answer, he does not know whether the mobile has moved out of range of the station, the mobile equipment is defective, the party called is out of his vehicle, or the base station is in trouble. Some time may elapse before he decides it is the latter and sends out a signal to switch the station to the standby equipment.

Transmitter Transfer As far as the transmitter is concerned, automatic standby operation is relatively easy to accomplish. (Figure 8) A RF pick-up can be coupled into the output circuitry of the transmitter, and a small sample of the RF power rectified and used to control a relay circuit. If the RF power falls below a preset level the relay contacts close. This closure could be transmitted to the control console and the dispatcher then could initiate the transfer to standby. However, it is more practical to have the relay in the RF level indicator effect the transfer directly at the base station, and have an indication of the transfer transmitted to the control console.

Initiating automatic standby in the case of receiver failure is more difficult. To satisfactorily check the receiver (Figure 9) the output of a low power, stable source of RF, modulated with an audio tone must be fed into the receiver input periodically. The level of the audio tone coming from the receiver is then a measure of its proper functioning. It is desirable to prevent such a checking circuit from interfering with an incoming signal. This can be done by automatically initiating checking from the console when the receiver is locked out if you have voting, or else by using a timer

at the base station which is disabled when the receiver C.O.R. is energized.

Since for many services the continuity of the outgoing signal is more important than the incoming signal, it is questionable whether the complexities added by receiver checking can be justified in most cases.

These are just a few of the considerations to be weighed in arriving at the control system. After this has been determined, we are then faced with the design of a control console to operate the system.

Console Design For such systems as we have been discussing, each console must be custom designed, although elements of design can be common. In the design of the console not only must the circuitry be considered, but the ease of operation, the possible use of more than one dispatcher for peak loads, the space available in the dispatch room, to name just a few parameters. It will be beyond the scope of this paper to discuss these design parameters.

Typical Console Design

To illustrate such a console, we have in Figure 10 the control console for the Massachusetts Turnpike. The Microwave backbone system provides duplex channels for each of seven base stations and eight control points, in addition to telephone and telegraph circuits and an alarm circuit.

The console is arranged with duplicate operating positions so that during the daytime separate dispatchers operate the Eastern and Western halves of the system. At night one dispatcher handles the whole system. You will note the two boom type microphones and treadle footswitches. All the panels swing down on piano hinges to give full access from the front for servicing.

(Figure 11) For each operating position the push buttons with indicator lights on the left provide for selection of base stations and those on the right are provided for selection of control points. Two parallel rows of buttons are provided so that two base stations or two control points can be selected at the same time. There are two audio channels in each half of the console with two speakers, with individual volume controls, and cut-off switches. Indicator lights show whether the channels are in use. A gain control is provided for the microphone and a switch to connect it to either channel.

The VU meter also has a gain reduction scale and a four position switch so that the system audio levels and amount of audio compression can be measured for either channel. An EN-30A Tone Dispatch unit is mounted in the console to provide for selective signalling of mobile units and interchanges, which are, in effect, fixed mobile units. A power switch and tape recorder receptacle complete the facilities on the panel.

The operation of the console can be better understood by reference to the simplified control console block diagram (Figure 12). Under standby conditions, the circuits are connected to the party or calling channel, through the voting panel. This unit serves as a base station selector. An incoming call from a mobile may be picked up by several base station receivers, but the voting panel provides that only one base station receiver is connected to the party-channel. The signal received on the party-channel is re-transmitted from all base stations and heard at all control points.

After the initial contact the dispatcher can transfer the call to channel 1, using the selector push buttons previously mentioned.

Rotary stepping switches actuated by the push buttons perform the necessary connect functions and actuate disconnect relays that take the selected stations and/or control points off the party channel.

(Figure 13) The party channel panel is located between the two dispatch positions. The top row of indicator lamps indicates from which base station an incoming call is coming. If a control point wants to call out he depresses his push-to-talk switch and this lights the appropriate light in the lower row. The lever switches in the upper row can be used to take the individual stations off the party channel, if they are causing interference with the system due to malfunctioning or to isolate sections of the system.

The lower row of lever switches can be used to take control points off the party channel if they do not wish to listen to the traffic. The lever switch at the upper left disabled the retransmit function so that the party channel can monitor all stations but incoming signals will not be rebroadcast.

An interchange or a mobile wishing to call another mobile or interchange calls the dispatcher to have the desired party selectively called and then be connected to use a single base station as a repeater or two base stations

to communicate if the distance so requires.

Other Specialized Control Circuitry

Mobile Telephone Systems

An entirely different form of control circuitry from those we have been discussing is required in the case of two-way dialling mobile telephone systems. Here we are not faced with elaborate consoles to control a number of base stations, but with a termination unit to convert the output of a telephone dial exchange into control and signalling functions for the base station transmitter. It also has to convert the signalling information from the mobile unit into signals compatible with the telephone dialling system, provide for reverberate ringing of a mobile unit in car-to-car dialling, and recognition of mobile identification code if required.

Remote Control Applications

There is another field of control circuitry that could attain large proportions if the FCC can find place for it in the land mobile fre-

quencies. In this field the radio is part of the control circuitry, rather than the control circuitry part of a radio system. This is the field of remote control. An illustration of this is given in Figure 14. This is a remotely controlled industrial yard locomotive, now being operated on a development license. It allows one man to do switching operations without climbing in and out of the locomotive and walking to and from switches, etc. The control console (Figure 15) contains a RF transmitter, tone transmitters and switches for the various locomotive functions to be controlled. The locomotive unit (Figure 16) consists of a radio receiver, tone receivers and relays to control the stepping relays that accomplish locomotive control.

From these examples it can be seen that control circuits are the nerves and the control console the brain that integrate a group of VHF equipments into a communication system.

The quality of the control circuitry design makes the difference between an inferior communication system and a good one.

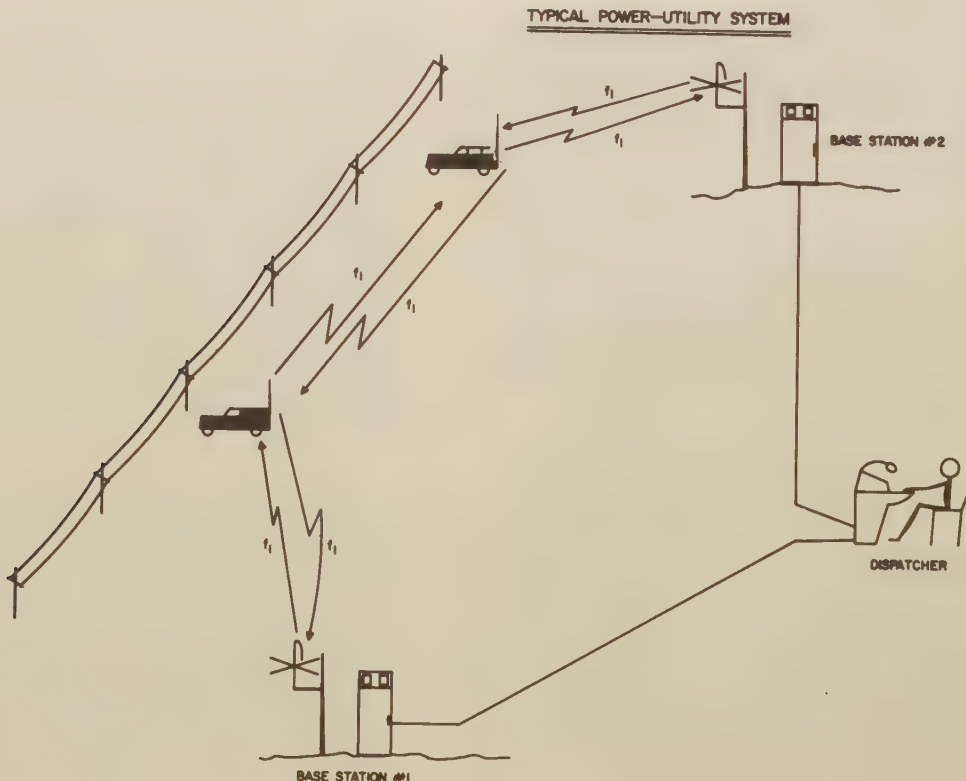


Fig. 1 - Typical power-utility system.



Fig. 2 - EC-28 remote control unit.

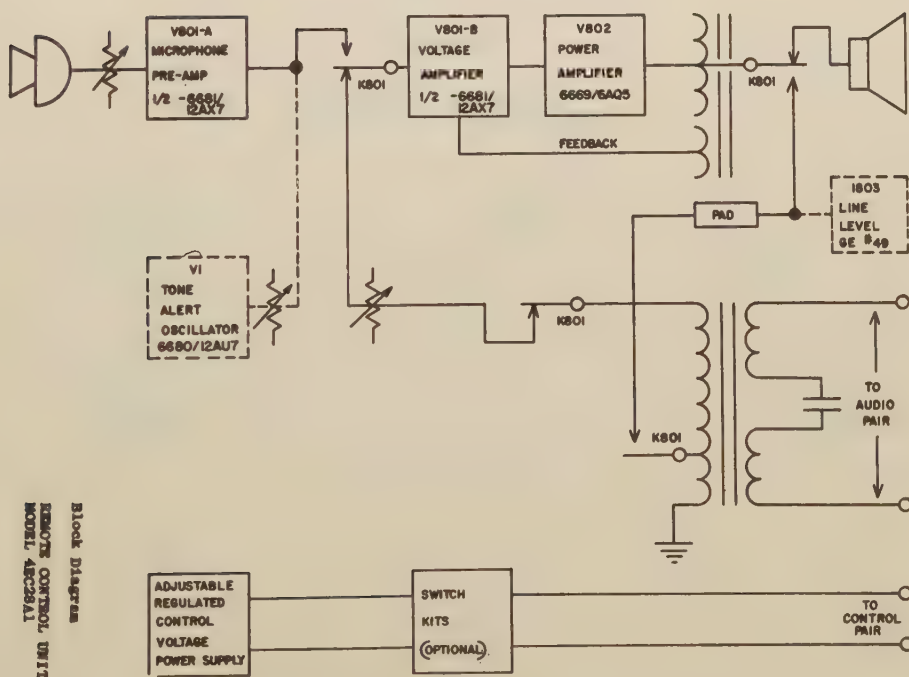


Fig. 3 - Block diagram - remote control unit.

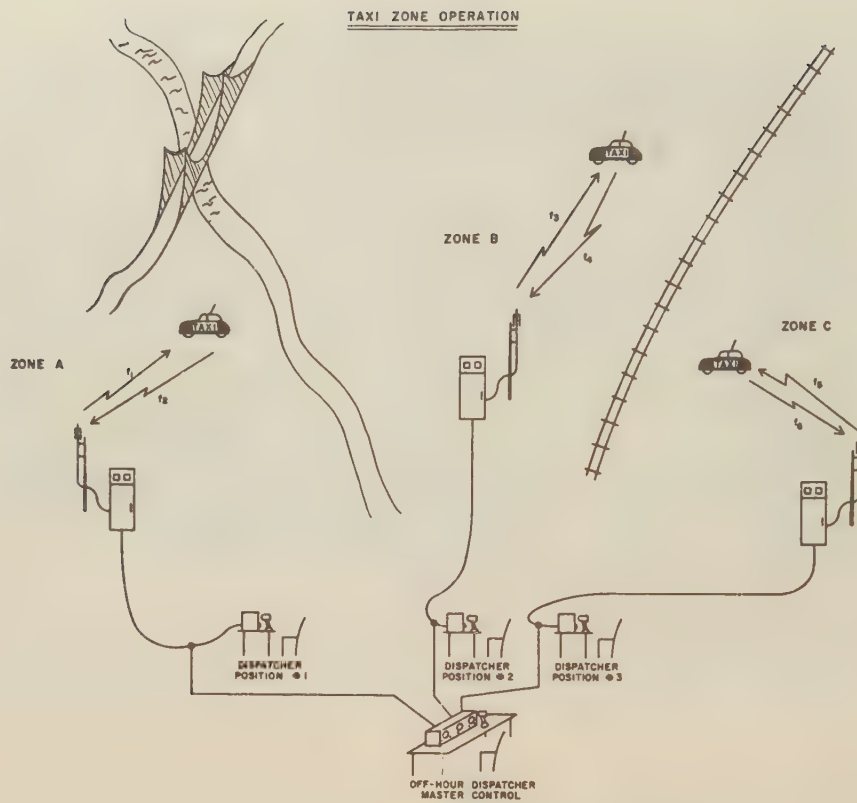


Fig. 4 - Zoned taxi system.

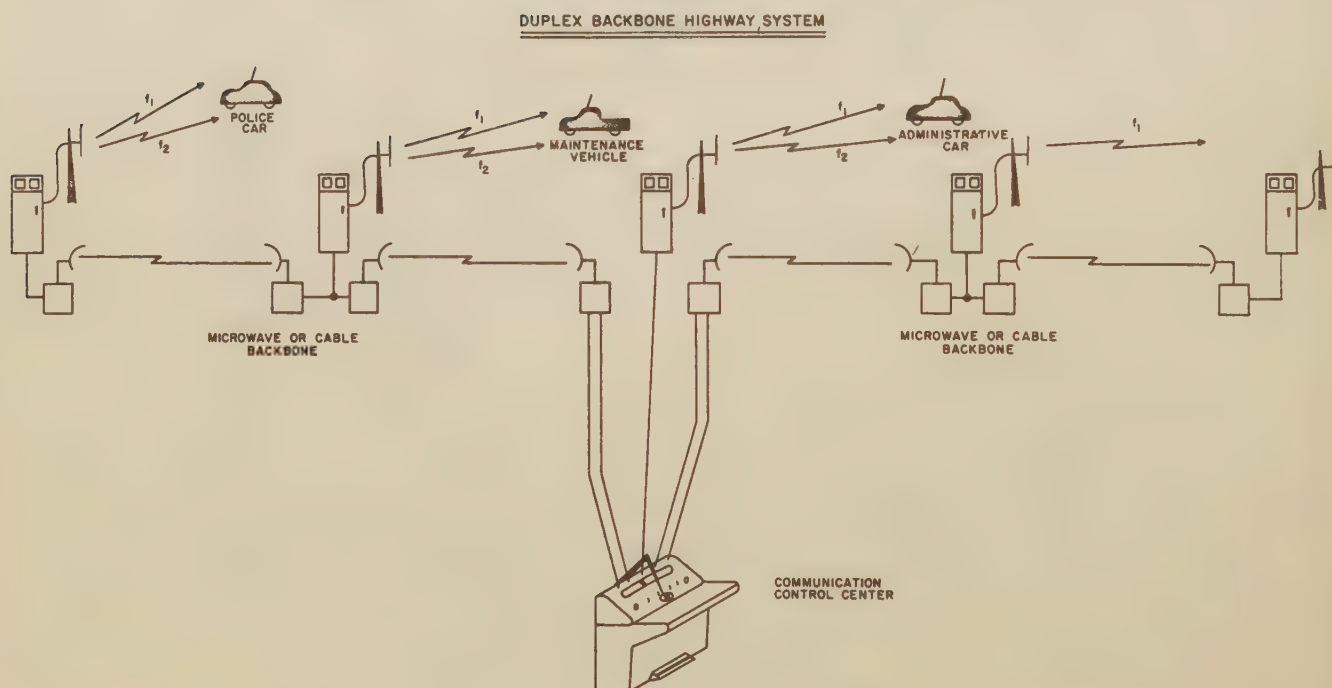


Fig. 5 - Duplex backbone highway system.

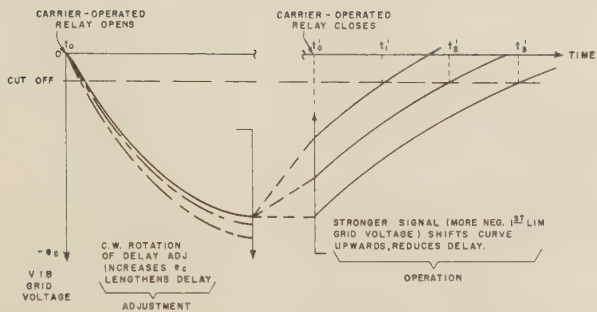


Fig. 6 - Schematic - voting delay panel.

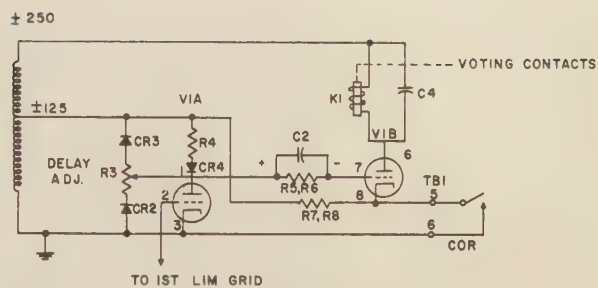


Fig. 7 - Graphic explanation of voting delay panel.

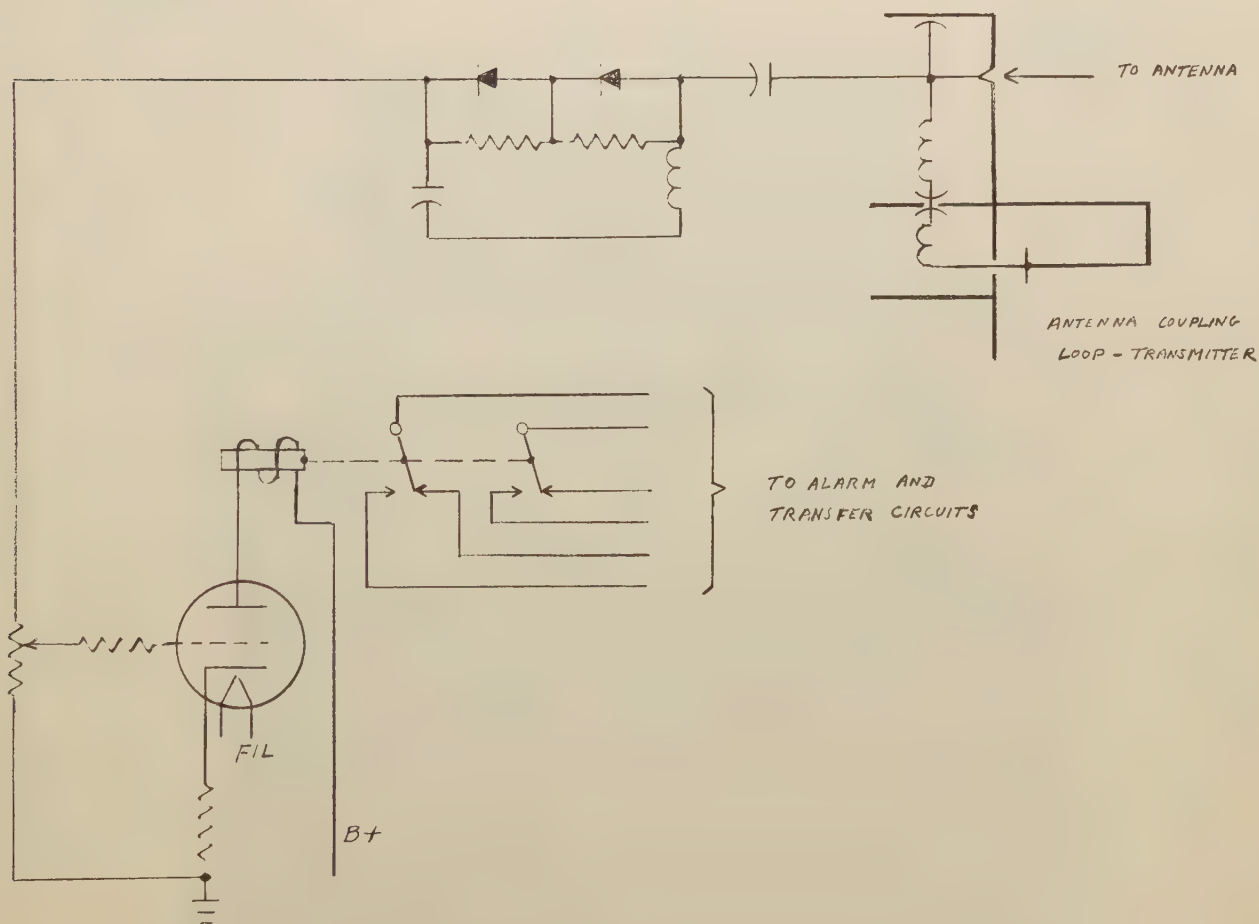


Fig. 8 - Schematic - RF power level indicator.

RECEIVER PERFORMANCE INDICATOR

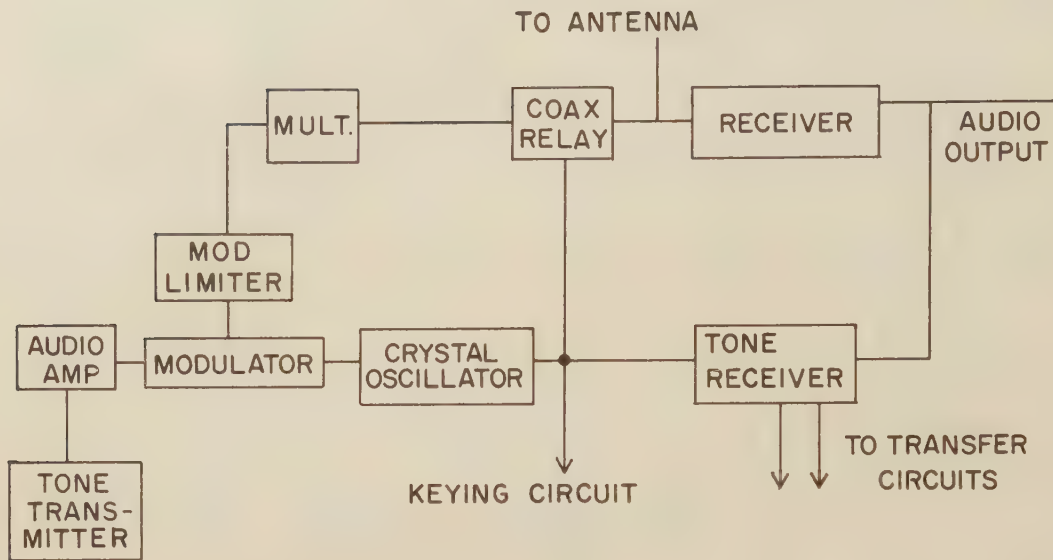


Fig. 9 - Block diagram - receiver performance indicator.

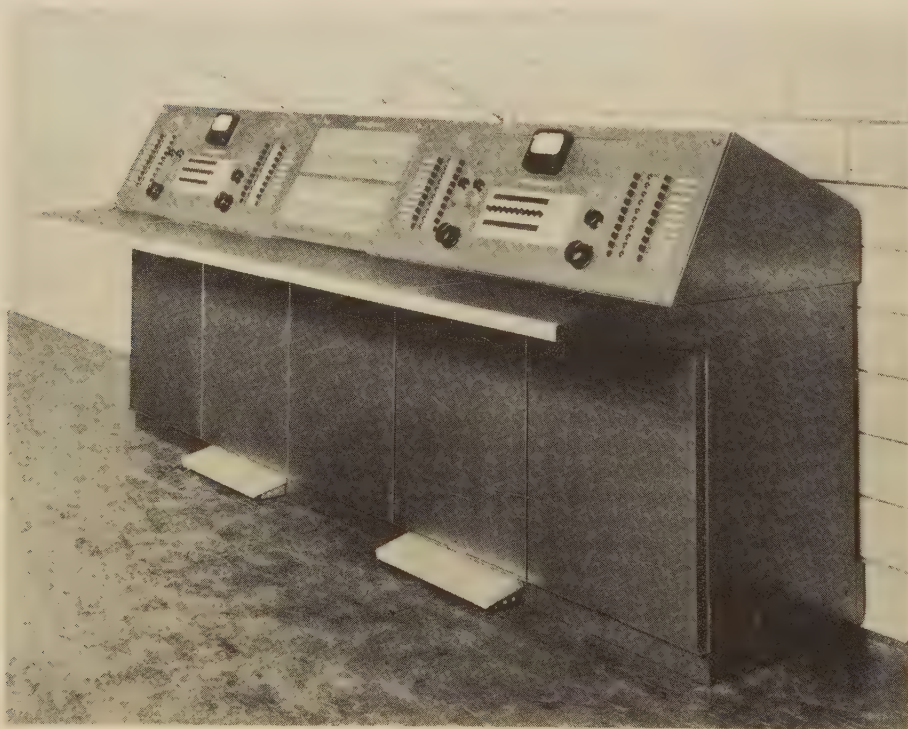


Figure 10 - Control console - Massachusetts turnpike.

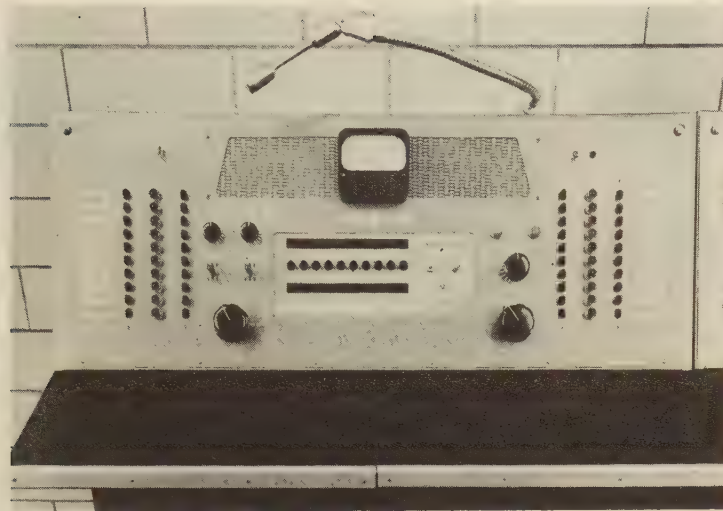


Fig. 11 - Operating position panel - control console - Massachusetts turnpike.

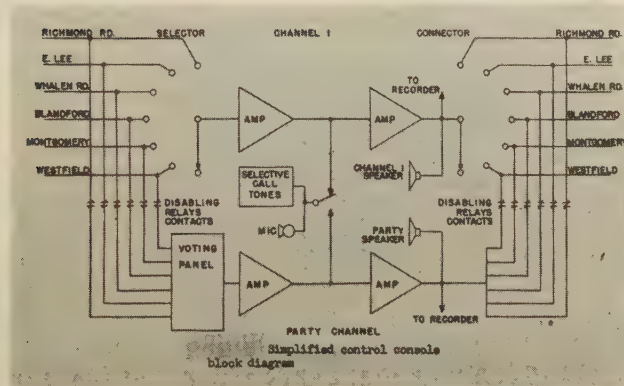


Fig. 12 - Simplified block diagram - operating position panel - Massachusetts turnpike.



Fig. 13 - Party-channel panel - control console - Massachusetts turnpike.

Fig. 14 - Radio controlled
industrial land locomotive. →

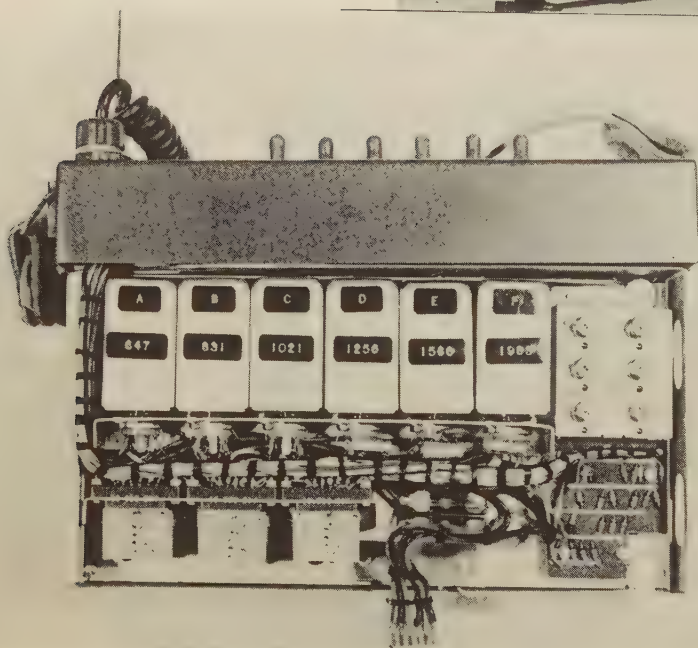
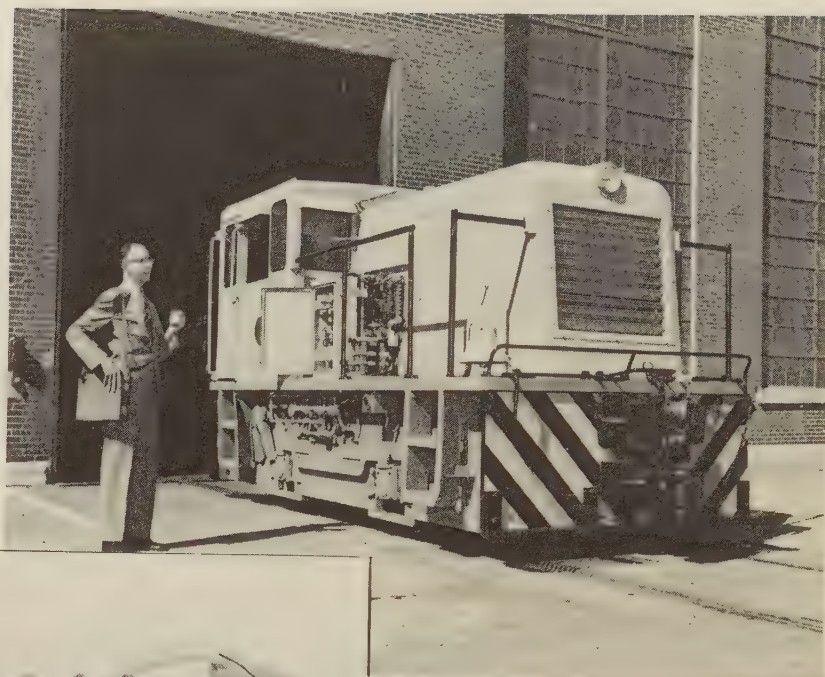


Fig. 15 - Portable control console.

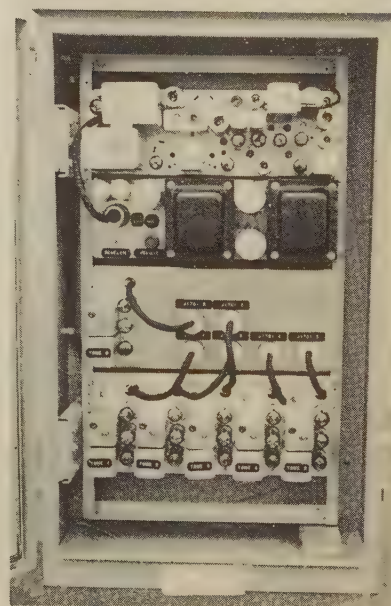


Fig. 16 - Locomotive receiver
unit.

A PROPOSED SYSTEM FOR 11 CHANNEL ACCESS
IN THE MOBILE TELEPHONE SERVICE

C. A. Rypinski, Jr.
Secode Corporation
San Francisco, Calif.

Abstract

A signaling, supervision and radio technique suitable for multi-channel access in the VHF MTS band is proposed. The logic is based on the continued use of 600/1500 cps transitional signaling and certain existing methods of transmitting supervisory signals to the base terminal. Mobile identification is provided but is neither required or excluded. The availability of a mobile radio equipment which does not deteriorate as a result of continuous channel switching is assumed.

Signaling tone at either frequency is used to mark the idle channel on which the next call will appear or on which the mobile may seize the terminal. If the mobile is not locked on a channel marked idle, the busy indication is given.

The logic of this technique is further detailed in a Table and is illustrated by tracing sequences of calls including special cases such as carrier fade, simultaneous seizure and the persistent caller with no answer.

To illustrate feasibility a suitable mobile decoder and control unit is described which provides decoding, supervision and logical control. Component content of this design is tabulated.

A possible configuration of a preferred mobile radio transceiver is proposed which employs synthesis type channel switching, linear detection and full duplex operation. The 13 crystals employed are shared by transmitter and receiver and only one is a high accuracy type.

It is the object of this paper to encourage the adoption of a multi-channel access standard to serve the interval preceding the development of the broad band service by showing compatibility with existing technique and the feasibility of the required equipment.

General

Important requirements to be satisfied by an ideal radio telephone system may be summarized as follows:

It must work like a telephone, even though a pushbutton business instrument.

It must be compatible with existing systems, and

It must increase the utilization of spectrum space to enable better and more available service.

It has long been recognized that if the mobile subscriber had access to any of a group of channels not only would the usage of those channels be improved, but also the grade of service expressed as delay in obtaining a connection. The problem has been a method of accomplishment which does not involve unacceptable penalties in some operating characteristics. While a substantial improvement in service has been obtained by introducing push-button channel switching, this does not result in the privacy and automatic operation characteristics necessary to satisfy the first requirement.

It is imperative that the industry agree on common control signals so that the needs of a traveling mobile may be satisfied. This can come about only after careful consideration of all known techniques, one of which is proposed in this paper.

Proposed is a set of standards for the inward and outward mobile radio telephone control signals, which are comprehensive and include as features not only trunking of all assigned radio channels, but full unit identification and a means of base selection for netted systems of overlapping base stations. This plan should be suitable for base stations furnishing service to 250 or more mobiles. The essence of the standard is the logic and to a lesser extent the coding of the signals and the selection of frequencies. The coding, however, is tightly coupled to compatibility considerations.

An important test for any logic is the reduction to practice, for it is this cycle which reveals overlooked points and indicates the economic implications of adoption. The results in component content of a theoretical design are offered.

No attempt is made in this paper to propose the

design of the central office control terminal. Rather, the mobile is fully described to define the requirements to be placed on this design.

It is important to note that the proposed system is not dependent on a particular form of transmission, or a particular number of channels. It would be applicable if a single base transmitter were used with channels derived on a carrier basis or on a full single sideband system. The only dependence placed on carrier information is that required to enable non-system or partially inoperative mobile to reach an operator.

Assumptions

Some of the assumptions underlying this system proposal are recited as follows:

- 1) Bell compatible transitional 600/1500 cps outward signaling to be employed.
- 2) Address and identification of the mobile is to be identical. The number of digits is not assumed.
- 3) Radio equipment at the mobile and base is full duplex. Transmitter on time may be limited at the mobile for battery conservation.
- 4) Continuous channel change in the radio transmitter does not result in wear or intolerable acoustic disturbance. Switching is accomplished by applying battery to one of N leads.

The information carrying capability of the 600/1500 cps transitional tone keying is very large and is limited by the bandwidth of the tone filters at the decoder. The bandwidth typically employed is appreciably greater than that employed by 100 wpm fsk telegraph receivers, that is, more than sufficient for a data rate of 100 bits/second. There is little necessity for additional tones to carry the control functions.

While the multi-channel access feature does not depend on the existence of full unit identification, busy information on a multi-channel central office terminal does. In addition, this identification is the only surely satisfactory system for distinguishing foreign area mobiles and billing them. The number capacity should be sufficient for each mobile to be uniquely identified.

Full duplex is important not only to obtain customary voice operation but to enable acknowledgment of mobile originated supervisory signals as soon as received or to immediately inform the mobile of aborted signaling. In addition, sidetone can be provided at the central office terminal to perform the classical

function of regulating subscriber voice level.

The use of base stations with overlapping coverage areas sharing the same channels is presumed. The selection of base station must then rest with the subscriber who alone knows his geographic location, and means must be provided him to enable identification of bases without reference to RF signal strength.

Method

The information which the mobile requires in a multi-channel access system is the channel on which his call will appear and the channel on which he may originate a call. It is possible to make these channels one and the same. This information is not identical to telling the mobile the channels on which he may not make or receive a call.

An available channel is defined as one which is not busy and which may be selected as a marked idle channel on which an outgoing call will originate or on which the next mobile seizure may take place.

The method proposed employs the signaling tone in the unkeyed condition to mark the idle channel. All mobile units seek the marked channel unless logically inhibited and follow the marking as progressive use is made of the RF channels.

As would be the case with a particular channel designated for signaling, there is no loss of communication capacity, for when the last channel is put in use, continuous search is equivalent to all paths busy.

With a channel reverting arrangement it is possible to use the signaling channel last, however, when one of the other operating channels finish there is no way of putting it to outward use until the home channel idles. Thus, there must be some loss of communication capacity. In addition, channel designation information equivalent to one more address digit must be transmitted.

A more subtle consideration is that the busy/idle decision is better made at the base than at the mobile. If it is assumed that a group of RF channels are to be shared by base stations at different locations, the inability of the mobile to hear the base transmitter is no longer assurance that the channel is available. Thus, any system which allows the mobile a choice of idle channels will suffer some penalty in a netted system of bases.

It is required that at least one base transmitter be on the air at all times and one more than is required to carry the busy channels. Before this point is decided to be a disadvantage, consider the busy/idle logic. The ability of the mobile to detect and lock-on the marked channel is a test of the usability of the path. A weak RF

signal from an adjacent area will not busy the channel if the base transmitter is sufficient to override.

It is to be demonstrated that all necessary logical instructions to the mobile may be obtained by control of the presence or absence of signaling tone. No meaning is assigned to one frequency or the other and the use of both at the same time is prohibited.

As a convention to convenience the central office terminal design, 600 cps is used for telegraph identification as the base transmitter goes off the air, however, the mobile unit would respond identically to 1500 cps. The same convention will apply to marking tone, but again the mobile will in no way depend on the selection of one frequency over the other.

Base station identification must be accomplished by coding of the marking tone in such fashion that no output is produced in the decoding section and that the tone presence detector is unimpaired. This is done by frequency shift keying the signaling tone at a rate beyond the cutoff frequency of the detector. Base stations may then be frequency coded at rates of 40 to 100 cps into 3 to 5 groups. Where the mobile receiver is able to detect idle channel marking from more than one base station, this identification becomes imperative.

The modulation code for base identification may well be the frequencies every 15 cps from 40 to 100 applied as a burst of 50 milliseconds, every 1000 milliseconds. This would enable the mobile logic to be designed to latch and release on the steady state signal which may be detected for presence or absence in less than 10 milliseconds. The low frequency tone burst would then be a bump signal for all mobiles except the one rejecting the particular frequency. This operation may be allowed a time constant of 50 or more milliseconds.

The important requirements which this scheme satisfies are, first it does not slow the marking tone absent release to channel search which is important on simultaneous seizure time resolution and second it may be deleted or added without affecting the balance of the system. It is also possible that the burst philosophy would be important if there were time sharing of an idle channel by different base stations.

Supervisory signals from the mobile are initiated by command and terminated by acknowledgment in the form of on/off keying of the base originated signaling tone. There are but two basic signals to be transmitted, namely, off-hook and on-hook. If a practice of transmitting at least (and also at most) two tones is adhered to, then 2 out of 3 frequency codes with one combination vacant results. Compati-

bility requirements might dictate the use of a 4th frequency not logically required.

The off-hook signal may also be used to carry pulsing information inbound, with one tone pulsed and the other used as dropout guard. This logic has been applied in constructing the statements displayed in Table I.

System Layout

To prepare for the description of call cycles, it is necessary to indicate system makeup at least to the input/output definitions. Referring to Figure 1, it may be seen that a mobile installation is composed of control head, duplex radio and mobile control unit. Wire lead functions leaving the radio and head are noted.

It is the function of the control unit to process the needs of the other two elements to achieve a telephone system. In addition to the logic the control unit contains circuits for pulse decoding, identification encoding, supervisory tone generation, channel switching commands, marking signal detection, base identification detection and timing.

The application of these functions will become apparent in tracing typical call cycles.

Operation

Call Cycles

The operation of the logic displayed in the proposed standards of Table I may be illustrated by tracing typical call cycles in a suitably designed system. Description of circuit technique for accomplishment is deferred.

When the radio is first turned on, it is probable the channel to which it is set will not bear marking tone. A search will be initiated tentatively at the rate of two channels per second until the radio comes to a channel marked idle. This marking should be detected at the time constant of about 10 milliseconds though the radio will look at each channel for 500 milliseconds. If base identification is applied, a tone burst will occur which will restart channel search unless the identification corresponds with that preset in the mobile unit.

On an outgoing call all mobiles in the system will be locked to the idle channel on which it is to originate. The coding of the base transmitter will start with a "one" pulse to guarantee clearance of selectors as is current practice. The first "one" will cause the busy lights of all mobiles in the system to come on and for those mobiles to become as a result unable to seize.

Pulsing will start and within 2 to 5 seconds one of the selectors will reach the contact pin and its call latch will be operated. One second after the contact pin has been reached, the base station will send another clearing pulse which will result in all mobiles having selectors reset to home. In addition, tone will be immediately turned off from the base for about 200 milliseconds. All mobiles other than the one addressed will go on search for the next marked channel. The unaddressed mobiles will be capable of seizing about 3 to 6 seconds after the start of out-going signaling.

There is no need for exclusive answer in this system since unaddressed mobiles are incapable of seizing the channel on which a call originates once pulsing has started. As soon as the mobile knows that it is not addressed it is placed on another channel, and therefore the system cannot be paralyzed by failure of the addressed mobile to answer.

The base station logic must be so arranged that signaling may not begin on a second channel until one code has been completed on the first channel. However, it is possible to arrange central office terminal signaling on any number of channels with starts stepped at intervals of 6 seconds. Simultaneously with start of signaling a new channel must be marked idle.

When the called mobile goes off-hook it originates off-hook supervisory signal tone, which causes the central office terminal to terminate transmission of signaling and connect the voice circuit. The removal of the signaling tone is sensed by the mobile which in turn terminates the transmission of the off-hook supervisory signal. No identification is necessary at this point since the base is certain of the mobile it is talking to.

At the completion of the call the mobile party goes off hook which causes the transmission of on-hook supervisory signal tone. The base transmitter sensing this supervisory signal causes morse identification to take place prior to the shut-down of the transmitter as required by FCC regulations. The morse transmission is sensed by the mobile for termination of on-hook supervisory signal. Should this acknowledgment not be received the mobile must timeout after perhaps 10 seconds.

When a mobile wishes to originate a call it is only necessary for the subscriber to observe whether or not the busy light is on. If the busy light is off he may go off-hook which causes the off-hook supervisory signal tone to be transmitted. This is acknowledged by the base transmitter removing the marking tone from the channel. The removal of marking tone causes all other mobiles to leave that channel. Thus,

the calling mobile achieves exclusive use of that radio channel in a cycle which typically may run about 50 milliseconds, the pickup time of perhaps 2 relays and 2 integrations. To create simultaneous answer problem it is necessary that both mobiles go off-hook within 50 milliseconds of the same instant. This number may be susceptible to reduction through improved circuit design.

When the off-hook supervisory signal has been acknowledged the mobile transmits identification with positive pulsing keyed on one of the supervisory tones.

It is possible to arrange the logic of a central office terminal to sense drop out on the guard tone during pulsing. In the event of such drop out the central office returns whizzer tone to indicate to the subscriber that his call has been rejected.

Certain special features appear in this system to enable full time operation of the radio receiver. The key switch will be two position - on/off. In the off position of the key switch it will be possible to receive calls but it will not be possible to originate calls. Make-up of the call latch on an incoming call will turn on the heaters of the transmitter tubes. The heater latch will not release until disconnect.

A point which is not clearly defined is the operation of the busy light. The nature of this indication is that it inhibits transmission and mutes the handset under any condition where the telephone circuit is unavailable. This means that during the call the busy light is off, contrary to the operation of lighted pushbuttons on standard subsets. It may be necessary or desirable after further study to provide an override which lights the light but releases busy functions during a conversation.

Should the subscriber go off hook, while the busy light is on, the busy circuit will become latched and the latch will not be capable of restoration except by return to hook. This is necessary to prevent users from going off hook and waiting until dial tone appears on the channel. With this possible, simultaneous seizure by a number of mobiles would be automatically timed.

Compatibility

This proposal is fully compatible with existing manual mobiles in that these units may be signaled and may reach an operator to originate a call. The multi-channel mobile will be able to operate with a manual base if only the channel switch is locked on the correct position, and supervision locked out.

In addition, a large measure of compatibility

exists with present inward dialing single channel systems. While it is not likely that single channel mobiles would dial through a multi-channel base (because of foreign area identity), this is a technical possibility since connect and disconnect supervisory signals are the same, and dialing similar.

It is then possible to envision a multi-channel mobile with a multi-position base selector switch coded for cities in which he wished to operate. Certain of these positions would put his radio in the single channel manual mode.

System Hardware

An effort has been made to embody this philosophy in a paper design, elements of which, however, have been built and tested. The radio and control head are purposely generalized, however, reduction to practice should be rapid in the face of need.

Control Head

Beyond the elements of a normal telephone handset, there are some controls and indications peculiar to the mobile telephone service. The key-switch is two position. In the off condition calls may be received but not originated.

Light indication is provided for transmitter on and busy. The base station selector switch may look very much like an RF channel switch, however, the function underlying is different. To the user this switch will be effectively similar to the pushbuttons on a multi-line subset.

Radio

In addition to full duplex capability, the radio should have low enough standby current drain to operate continuously and transmitter heaters which reach operating temperature while the bell is ringing. Operation of any of N channels should result from furnishing battery to one of N leads.

Certain current design techniques may be applicable to an MTS radio, as for example synthesis type injection frequency generation enabling shared use of a low accuracy crystal bank between transmitter and receiver, and phase lock FM detection as developed for recovery of FM-FM telemetry from space vehicles.

It may be noted that while these refinements are very attractive it is readily possible to adapt existing 4 channel radios to this system as well.

Mobile Control Unit

The mobile control unit collects information from the radio and control head and processes it logically into instructions returned to the other units. The major elements of the mobile control unit are shown in Figure 1 and are:

Decoder/Sender Section
Tone Detector Section
Tone Oscillator Section
Logic Section
Channel Switching Section

Decoder/Sender Section

This section of the mobile control unit provides address sensing, identification and certain other logical functions. It is contemplated that this section will use an electro-mechanical counting device such as the Secode Model 70 Selector. The address sensing function of this unit is accomplished by comparing the incoming pulse train with a count combination mechanically preset into the selector. Successful addressing results in the closure of a contact. The selector may, in addition, be fitted with off normal contacts, the purpose of which is to indicate that a count is in progress and pulse sending contacts.

The sender function of the decoder is accomplished by switching the already present circuit elements. The circuitry may be arranged to generate a pulse train which is terminated for a brief interval each time a code pin on the selector is reached. It is possible to modify the selector in such fashion that additional digits are sent in the transponding mode as compared with those set in for the address sensing mode.

The circuit elements of which this unit is composed are the tone filters, polar detector, low pass filter, low hysteresis trigger circuit, full wave rectifier, one shot pulsing relay, and identification latch relay. The output of the polar detector is furnished in addition to the tone detector section for other logical uses.

Tone Detector Section

The tone detector section rides the output of the polar detector in the decoder sender section. The tone detector is a trigger circuit so arranged that a departure from reference level in either direction will result in current flow in the output half. This current will be used to close directly the fast response tone relay and through a diode and capacitor also the slow release tone

relay. With this circuit arrangement the characteristic is obtained that triggering does not depend on whether the signaling tone is at the 600 or the 1500 cycle position. The slow release relay is necessary to hold the tone present indication when signaling is notched off at the end of each address code.

The base identification circuit is also part of the tone detector section and likewise rides the output of the polar detector. It is arranged so that any AC frequency between 40 and 100 cycles will close its output relay, except a single frequency notched out by a resonant trap, triggering channel search.

Channel Switching Section

This section consists of a two pps pulse generator driving a pulsing relay, and which may be turned on and off by control of applied battery. The pulsing relay is used to advance a 12 position stepping switch or possibly an electronic equivalent which in turn controls the selection of channels in the radio.

Logic Section

This unit has relays, diodes, capacitors necessary to accomplish the logic of the system. It accepts the information generated in the radio and control head as well as in the balance of the mobile control unit, and originates all necessary command signals. The relays of which it is composed are 2C and 4C control relays and 1A reed relays.

A measure of contact saving is accomplished by the use of diodes and certain continuous signals are turned into momentary signals by use of capacitors. Latching as a function is accomplished without the use of make before break contacts. Within the logic section is a supervisory timer and the two tone oscillators necessary to originate mobile supervisory signals.

Component Content

A relay tabulation for the mobile control unit is shown in Table II based on the logic schematic of figure 5. Taken with this a component complement of cost producing elements has been approximated as follows:

1A Relays	11
2C Relays	4
4C Relays	4
Diodes	19
Transistors	17
Electrolytic Capacitors	10
Selector	1
Stepper	1
Tank Circuits	5

This amount of circuitry, it is estimated, could be housed in a box 4 x 6 by about 5 or 6 inches high.

Commentary

Shown in Table I are Standards for base and mobile characteristics which will make an automatic multi-channel trunking system possible. This standard is an attempt at specifications which will bring about a truly national mobile telephone service. To reach this objective, it is necessary that every mobile and every base station speak the same language in both directions.

Past practice by companies has been to present papers on new systems concurrently with availability for sale on the commercial market. Such a procedure intrinsically creates conflict in a commercial sense for one company is then in a position of having a "scoop" and prevents as a practical matter standardization on the technique in which a single company has excessive advantage.

In presenting a proposal for a system which has not yet been developed and which is not now for sale, I hope that it is possible to use the content for the basic cooperative discussion necessary for achieving these or some other uniform national standards for the mobile telephone service.

It is apparent that the simplicity of the mobile control unit just described depends to a certain extent on the use of a particular proprietary device. However, I do not believe that anyone can seriously allege that this device is the only practicable way to decode telephone dial pulses. I hope that the intent of the description of the multi-channel mobile control unit will be correctly understood. It is intended to show that the adoption of certain standards and logic results in realizable and practical equipment. A particular design exists only on paper. It is to be expected that should such logic as I have shown here be adopted, that actual equipment will differ substantially.

I do not believe it is necessary to pick up each of the logical pieces necessary for the accomplishment of multi-channel access and collect these points in a box called computer and assign a transmission channel for its output. What is required is a very close look at how much information is to be moved in each direction and particular care exercised to see that none is redundant or added for having accomplished some other step in less than the best way.

A number of important problems have been touched on either lightly or not at all in the preparation of this paper, but which are very significant factors in the accomplishment of the multi-channel access system, particularly the central office terminal and multiple transmitter intermodulation. These should not be considered as overlooked or insoluble problems, but rather subjects for additional study.

The preparation of this paper has been largely a process of collection and assimilation of system considerations and techniques which have come from many different sources. Most particularly I am indebted to members of the Bell System for the opportunity to discuss this problem. In addition, important contributions have been made by members of the Secode Engineering staff, particularly Messrs. C. E. DePuy and R. B. van Gelder. Without these contributions there would be no proposal and because of them the proposal has considered many factors often overlooked.

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This unit is hypothetical, but illustrates a possible transceiver configuration with shared lower accuracy crystals in the channel bank.
- 3 Photograph--Electro-Mechanical Selector modified for Sender Use.
This selector is similar to a commonly used type except that flag actuated sending contacts are mounted on the upper door.
- 4 Schematic Diagram--Decoder/Sender Section
This schematic illustrates the means of sharing common circuitry between decoding and sending functions.
- 5 Schematic Diagram--Logic Section
The logic shown is imperfect, but is reasonable in determining relay count and function as displayed in Table II.

TABLE I

PROPOSAL

MULTI-CHANNEL ACCESS SYSTEM STANDARDS

- 1. From a single base station, one and one only non-busy RF channel shall be marked idle by the presence of signaling tone (by convention 600 cps) indicating the channel on which the next outgoing call will be addressed or on which the next seizure may take place.
- 2. Outward signaling shall be transitional 600/1500 cps with transitions spaced 60 ± 5 milliseconds and interdigit interval of greater than 225 milliseconds. A reset 'one' shall be transmitted before each code and one second after the last pulse in the code. Signaling tone shall be shut off for 200 milliseconds after the last reset 'one'.
- 3. One channel shall be marked idle at all times considering that a channel is busy when outward pulsing starts.
- 4. Mobile logic shall employ a call latch to put the mobile in the answer mode which is made up from the first detection of the coding until either off-hook or abandonment of ringing indicated by absence of signaling tone for more than 200 milliseconds.
- 5. Mobile logic shall initiate channel search within 30 milliseconds upon loss of signaling tone except when inhibited by the call latch or off-hook. Search will be initiated by seizure from another mobile, notching of signaling tone after rejected code, or loss of an RF signal.
- 6. Mobile logic shall employ a busy indicator which will be on whenever the mobile is not locked on idle channel or while incoming signaling is in progress. The busy indicator shall inhibit transmission despite off-hook and shall mute the handset. The busy indicator shall be latched by off-hook and restored only by on-hook.
- 7. Mobile to base supervisory and dialing signals shall be formed entirely on a two out of three tone code transmitted until acknowledged but not more than 10 seconds. Tone frequencies are defined: F1=1100, F2=1300, and F3=1700 cps.
- 8. Mobile originated tone code is defined as follows:

Off hook F1 and F3 and not F2

On hook	F2 and F3 and not F1
Identification	F1 pulsed F3 guard (off normal) and not F2
Dialing	F1 pulsed F3 guard (off normal) and not F2

9. Mobile address and identification shall be a single 7 digit number. A smaller number of digits may be used if conversion to 7 digits is accommodated. Transmitted pulses may number 2 to 11 and will be one more than the assigned number. One pulse shall be reserved for clearing of pulse decoder.
10. Mobile identification shall start when seizure is acknowledged. Identification will be positively pulsed on F1 while F3 is on continuously from start to completion. Central office will return dial tone upon successful completion of identification.
11. Mobile dialing may start when dial tone is received. Tone F1 shall be on when pulsing springs are open and F3 shall be on when the dial is off normal. Central Office logic shall count off transitions.
12. Central Office logic shall acknowledge off hook by termination of marking or signaling tone, on hook by transmission of tone telegraph identification at 600 cps.
13. Central office terminal logic shall require positive absence of the third supervisory frequency.
14. Central office terminal logic shall observe guard tone during identification and dialing pulsing and in the event of dropout reject the call and return whizzer to the mobile.
15. Mobile audio system to be 4 wire with sidetone introduced at the central office terminal at a level suitable for the regulation of subscriber speaking volume.
16. Central office terminal shall store the numbers of listed mobiles. Foreign area mobiles identification shall be registered. Connection of foreign area mobile to dial tone or operator to be user option.
17. Central office terminal shall store numbers of busy mobiles and return busy signal to landside callers.
18. Mobile to mobile calls shall not be treated as reverting, but rather shall employ two radio channels.
19. Mobile radio shall be full duplex except that press to talk or voice operated relay may be used for transmitter control.
20. Base stations may be coded into five groups to enable selective seizure by a mobile within range of more than one. The base identification signal shall be a burst of 50 milliseconds applied once per second as frequency shift keying of the signaling tone at a coded rate. Mobile logic shall initiate channel search if received rate does not correspond to the preset value of the mobile. Keying rates of 40, 55, 70, 85 and 100 cps are employed.
21. Central office logic shall recognize carrier present and failure to connect with operator call.

TABLE II
MOBILE CONTROL UNIT RELAY TABLE

<u>Function</u>	<u>Code</u>	<u>Contacts</u>	<u>Type</u>		
			1A	2C	4C
<u>Logic Section</u>					
Busy	BSY	2A, 1B			x
Transmitter Control	XTC	1A	x		
Disconnect Latch	DL	2A, 1B			x
Call Latch	CL	2A, 1B, 1C			x
Hookswitch Repeat	HKS	1A, 1C		x	
Heater Latch	HL	2A		x	
Timer Start	TS	2A	xx		
Supervision Timer	SVT	2A	xx		
Dial Pulse Repeat	DPR	1A	x		
Sender Pulse Repeat	SPR	1A	x		
Identification Initiate	IDI	1A	x		
<u>Tone Detector Section</u>					
Signal Tone (fast opr.)	STF	1A, 1B		x	
Signal Tone Slow Release	STS	1B, 1C		x	
Base Identification	BID	1A	x		
<u>Decoder/Sender Section</u>					
Identification Latch	ILR	2A, 1B, 1C			x
Pulsing Relay	PR	1A	x		
<u>Channel Selector Section</u>					
Channel Trigger Generator	CTG	1A	x		
<u>Total Relay Complement</u>					
Reed Relay 1A			11		
Control Relay 2C				4	
Control Relay 4C					4

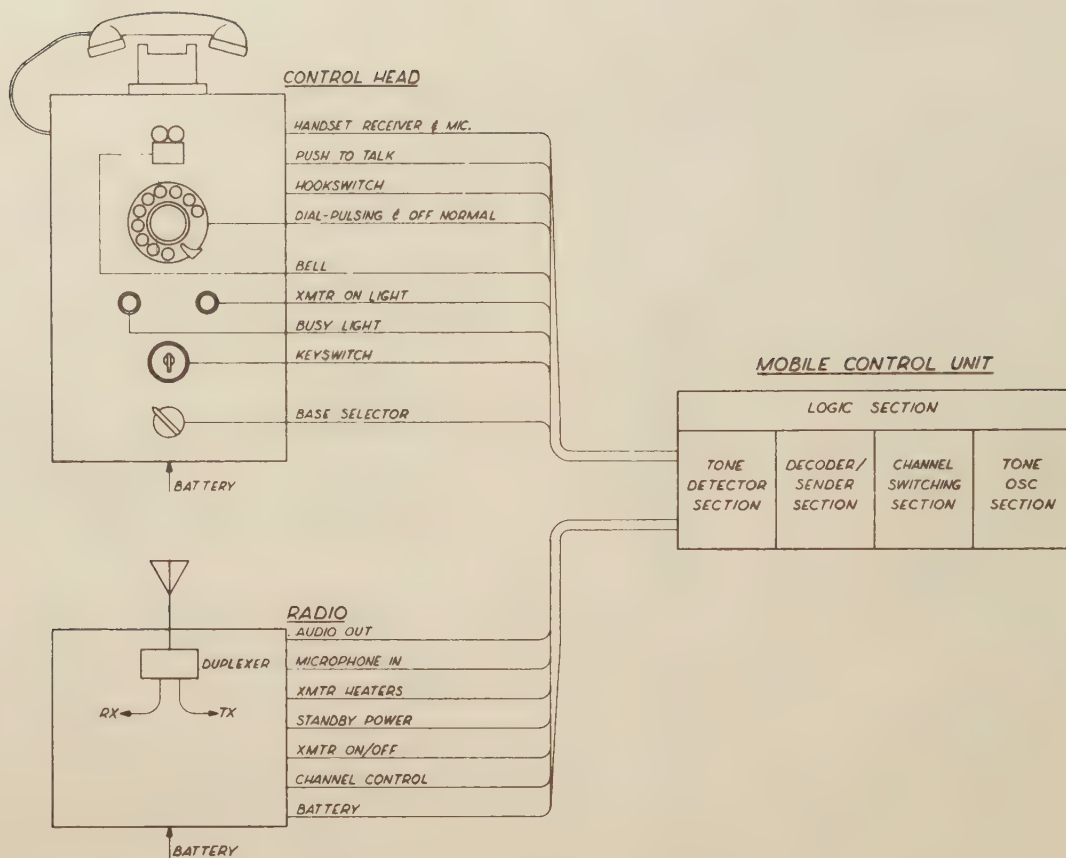


Fig. 1 - Block diagram, multichannel access mobile radiotelephone system.

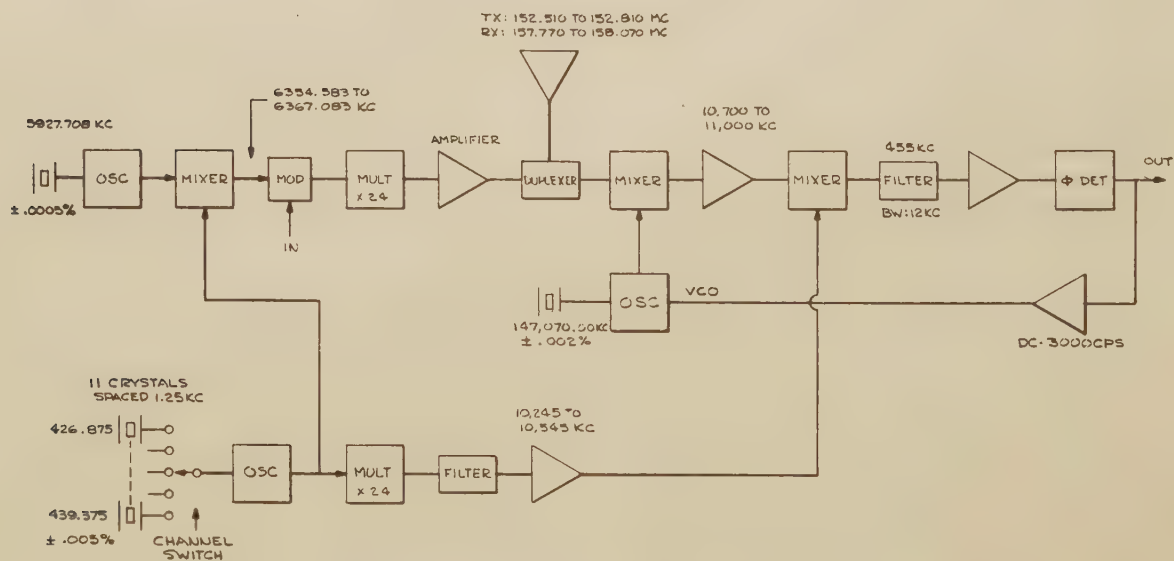


Fig. 2 - Block diagram 11 channel synthesis transceiver.



Fig. 3 - Photograph, electro-mechanical selector.

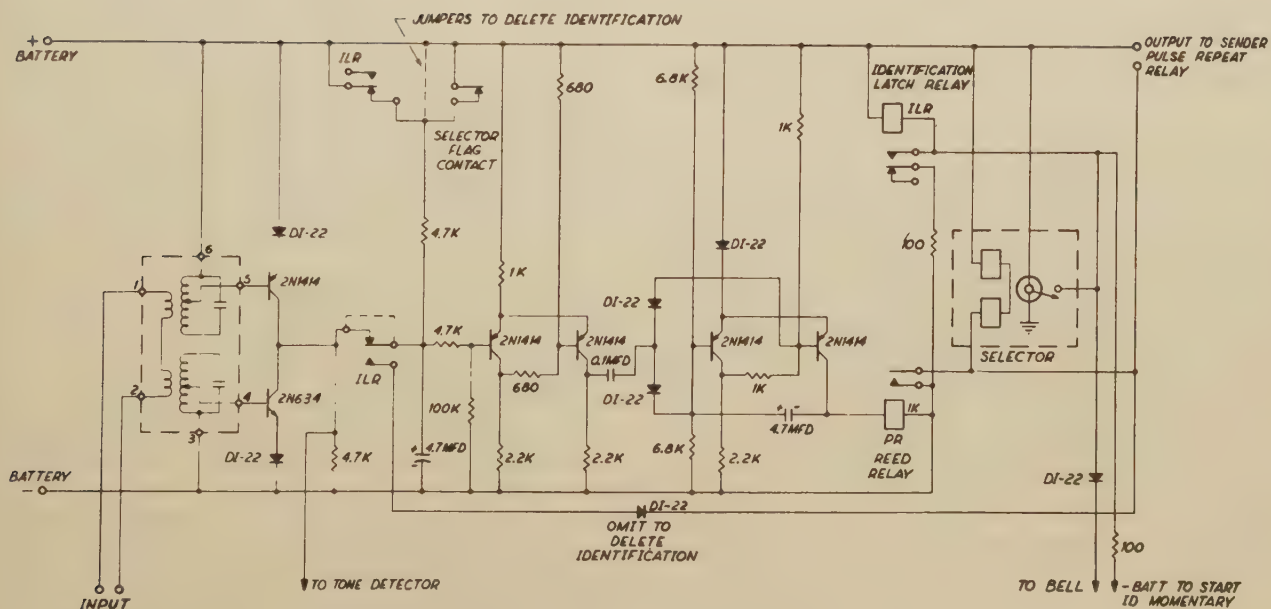


Fig. 4 - Schematic diagram, decoder/sender section.

LOGIC SECTION

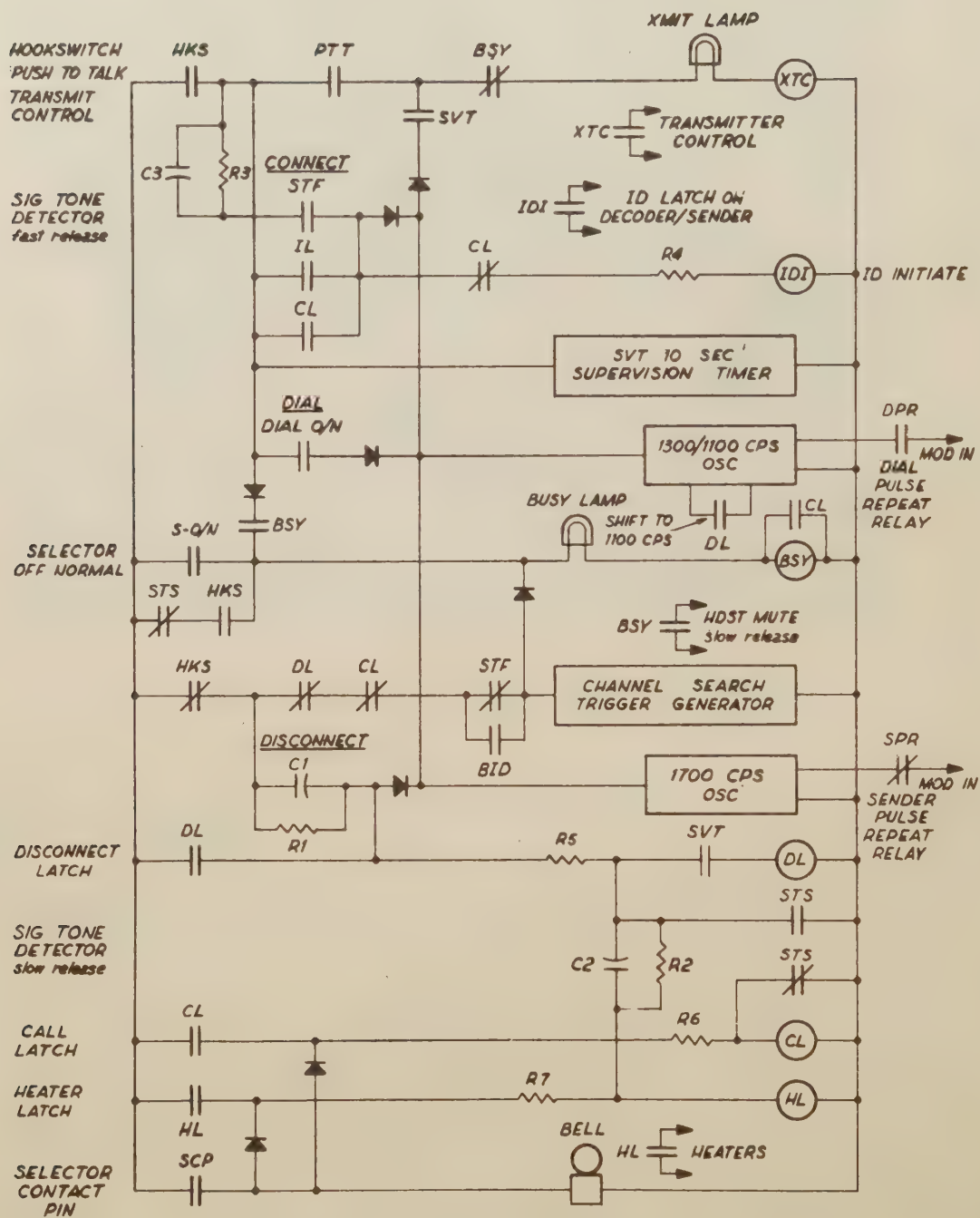


Fig. 5 - Schematic diagram, logic section.

THE USE OF LEVEL CONTROLLING DEVICES IN THE RADIO-TELEPHONE SERVICE

L. E. Getgen
Lenkurt Electric Co., Inc.
San Carlos, California

SUMMARY

This paper introduces the subject of speech level control as applied to radio-telephone service by presenting statistical data describing talker level variations and anticipated levels at the telephone central office. Because speech measurements are difficult to make, mention is made of speech to sine wave relationships that are convenient for system line-up. Next, maximum levels are established for the output of the controller and application to the wire-line or the radio transmitter.

The operational characteristics of three available types of level controlling devices are discussed. These are: the Agamp and Vogad which were designed specifically for control of speech levels into radio transmitters; the clipper-limiter commonly used in radio broadcasting; and the Compandor which is familiar in telephone applications.

Recordings were made of these devices in operation. Analysis of these recordings as related to the "ground rules" established in the text allowed conclusions to be drawn concerning the most advantageous use of each.

In discussing the use of level controlling devices, it is necessary to determine the nature of the signals that are to be controlled. Where telephone facilities are to be used, consideration must be given to plant practices. These practices as well as the transmitter input requirements will establish the output level limits for the device. Having an idea of the input and output requirements and taking into account unusual noise and environmental conditions, the next step is to examine the characteristics, and cost of available units to determine the extent to which they meet the system application.

SPEECH CHARACTERISTICS

Speech because of its random, complex, intermittent nature and because of the wide variations between talkers is difficult to measure. As a result, it is best treated on a statistical basis and then related in power, frequency content, and peak factor to a sine wave equivalent. The sine wave, being easy to duplicate, can then be used for testing or line-up purposes. It is easy to see that these sine wave equivalent values will often leave much to be desired in duplicating the effects of speech. Also obvious is the fact that statistical data in order to be of value must be derived from a large num-

ber of observations. In instances where it is not practical to make sufficient measurements to be of statistical value, one must either rely on data taken by others or make an estimate. Some of each was done here.

Assuming that speech levels for all talkers follow a Gaussian distribution, the number of talkers falling within various deviation ranges from the normal are:

<u>RANGE</u>	<u>% WITHIN $\pm \sigma$</u>	<u>% OUTSIDE $\pm \sigma$</u>
1 σ	68	32
2 σ	95	15
3 σ	99.7	0.3

This is indicated graphically in Figure 1.

The range from a soft whisper to a loud shout is about 60 db with a standard deviation of 10 db. Fortunately when people use a telephone or microphone they tend to neither shout nor whisper and the standard deviation averages 5.5 db. Another favorable factor is that a low level talker when speaking over a high loss circuit tends to speak louder and that the loud talker will not, when using the same circuit, increase his level in the same proportion. This results in a more favorable deviation range than we might anticipate. A similar tendency occurs on a noisy circuit. Due to effects like this, the standard deviation for telephone circuits may vary between 5.2 and 6.5 db.

From these figures, it would appear that a level controlling device having a 33 db range would accommodate 99.7% of the mobile radio users. However in many installations there will not be a fixed loss in the facilities between the point at which the speaker is located and the point where the level controlling device is installed. For instance a level controlling device located at a particular telephone office might receive level differences of 8 db or more for calls initiated from various locations even though the same person was making each call. Also, it is necessary to recognize that each individual, although being assigned a specific location statistically in the level distribution diagram, actually covers a range of levels when speaking. This is clearly indicated by observing vu meter behavior when monitoring a speaker. Thus, a 40 db range may be a more ideal goal to strive for if near perfect level control is desired.

Having established the range of speech levels that is to be expected, the next requirement is to determine the average level at the place where the level controlling device is to be located. In the common-carrier mobile radio service the level controlling amplifier is usually located at the central office. At this point the average level is -19 vu where the vu meter has been calibrated to read zero across a 600 ohm load when driven by a 600 ohm, 1 milliwatt, 1000 cps supply.

Another convenient relationship specifies the talker level at the switchboard in dbm rather than vu. According to this, the average talker at the switchboard has a speech power of -16 dbm, and the +3 talker is at zero dbm.

For convenience in relating speech peaks to the clipping point of amplifiers within the system, the peak factor for speech as read on a vu meter has been taken as 10 db. As a sine wave has a 3 db peak factor, a sine wave having a dbm level 7 db greater than the speech vu level would have a peak value equivalent to the speech.

TELEPHONE FACILITIES

Having discussed the inputs to the level controlling device, the next consideration is its output. Where the output is to be applied to telephone facilities the level should be low enough to prevent crosstalk in adjacent communication channels and to keep speech peaks below the "breakpoint" of repeaters and amplifiers. These levels must be patterned to meet particular system requirements and will not be discussed here except to stipulate that the maximum output level will be 0 vu. Where the circuit is not entirely wire-line, it will be assumed the line-up instructions will trim this level to meet the demands of devices in the signal path to the transmitter.

Because circuit noise conditions may, in a particular installation, be the most important factor in selecting the proper level controlling amplifier, a few comments will be made concerning noise measurements. These will be referred to in subsequent discussion of the AGAMP, VOGAD, Clipper-Limiter, and Compandor.

Noise measurements in the telephone field are made in reference to a power level of 90 db below 1 milliwatt at 1000 cps. These may be made on a "flat" meter and expressed in dbrn (db above reference noise). Or they may be made, as is usually the case, with a weighting network that takes into account the relative disturbance effect of noise frequencies in a communication system. The two networks used in the United States are based upon the response of the type 144 and the type F1A telephone sets. The respective weighting curves are shown in Figure 2. Noise measurements made with the 144 network are expressed in dba, 144 weighting, (db above -90 dbm). As the F1A handset is 5 db more sensitive than the 144 handset, measurements with it are expressed in dba, F1A weighting, (db above -85 dbm).

In the common-carrier mobile service, line noise will normally be less than 26 dba using F1A weighting. Because higher noise conditions will influence the choice of level controller, system line-up, and quality of service, the noise level should be checked in each installation.

THE TRANSMITTER

Ultimately the signal level at the transmitter must be established. Curves for a typical transmitter, Figure 3, show the clipping point as -15 dbm for a 1000 cps tone. Using the peak factor for speech of 10 db, the maximum input level without clipping would be -22 vu. Listening tests on this transmitter show the speech distortion to become quite noticeable when the input is higher than -19 vu. Also, the listening test shows that levels below -50 vu are not usable.

It is apparent that the goal is to maintain the transmitter input at -22 vu with as little deviation as possible.

LEVEL CONTROLLERS

Now that conditions have been established at the input of the level controller and at the transmitter input, it is of interest to investigate the characteristics of some devices that are commonly used for level control. One device, the AGAMP -- Automatic Gain Adjusting Amplifier -- or VOGAD was developed specifically for radio applications. Another, the clipper-limiter finds frequent use in the broadcast field. The Compandor is well known in telephone applications for signal-noise ratio improvement. It appears to have merit in modified form for mobile radio service.

THE AGAMP AND VOGAD

The characteristics to be described apply in detail to the Lenkurt AGAMP -- Automatic Gain Adjusting Amplifier. However they are generally true of the Western Electric VOGAD. For most applications the two are operationally interchangeable.

The AGAMP is shown in functional block form in Figure 4. The principal speech path is thru the input attenuator, preamplifier, variolossor, and output amplifier. When the attenuator is at zero loss, the unit is designed to accept a 40 db speech range of -54 to -14 vu. The attenuator can be increased in 4 db increments to 20 db where the acceptable 40 db input range is from -34 to +6 vu. Other loss positions allow the input range to be selected between these two limits.

Following the attenuator is a two-stage transistorized preamplifier having 25 db of gain. It is the purpose of this amplifier to increase the signal level so that in its subsequent journey through the variolossor, it does not drop into the noise level.

The variolossor is a multi-diode arrangement that offers loss to the signal in accordance with the d-c current through it. The loss ranges from 9 to 50 db. The method by which the variolossor d-c control current is derived is the heart of the unit.

The signal after attenuation by the variolossor, is fed to a three-stage transistorized amplifier. This amplifier has 44 db of gain and a breakpoint of +9 dbm. It provides a 0 vu signal to the output terminals.

Overall response of the signal path (input attenuator, pre-amplifier, variolossor, and amplifier) is shown in Figure 5.

Figure 4 shows that the signal is sampled at the pre-amplifier output. This sample is fed to the threshold level control. The setting of this control determines the level at which gain increasing action is initiated. For signals or noise below the threshold level, no gain increasing action takes place. Inputs above the threshold level pass through a two-stage amplifier and a 1.2 kc filter. Because of this filter, the signal sample is taken at a frequency that is representative of speech and is desensitized to frequencies outside the speech range.

There are two outputs from the 1.2 kc filter. One output passes through a syllabic filter that is tuned to approximately 7 cps. This filter restricts the gain-increase action to syllabic speech only. Therefore, the gain increaser is sensitive primarily to speech inputs and offers a high degree of rejection to random noise and sine wave inputs. The syllabic output is rectified and supplied to the d-c combining network as a source of control current for the variolossor regulation.

The other output of the 1.2 kc filter is applied to a proportional control circuit. Output of this circuit is proportional to the difference between the signal and threshold levels. For a signal level equal to threshold there is no proportional control circuit output. When the signal reaches nominal input level, the output of the proportional control circuit equals in magnitude the gain-increaser output. It is however, of the opposite polarity, so when applied to the d-c combining circuit, it completely cancels the gain-increaser output.

In addition to determining the amount of gain-increasing action, the proportional control establishes the time required for the signal to reach full output level. This time is somewhat inverse to the signal level. For example, it requires 16 syllables to reach full output when the signal input is just above threshold. For high signal levels, the time required to reach full output decreases as depicted in Figures 6 and 7. This reaction time provides considerable protection against going to full gain on noise because at the lower signal levels, where the likelihood of encountering noise is greatest, more time is required to reach full output.

To obtain the waveforms of Figure 7, a 1 kc sine wave was interrupted at a 7 cps rate. This waveform approximates syllabic speech and still depicts graphically the gain increasing action. Although Figure 7 represents inputs at only threshold, nominal, and maximum input levels, a complete series of waveforms was measured in order to plot Figure 6. This graph shows that signals below threshold are entirely ignored by the gain increaser, that the attack time decreases with increasing signal level, and that the reaction to signals above nominal input level is essentially instantaneous.

In the control circuit, a d-c voltage from a voltage divider (idle gain adjustment) is also fed into the d-c combining circuit (see Figure 4). It is the function of this adjustment to set the idle (no signal) gain.

The fourth input to the d-c combining circuit provides gain decrease action. This input is derived from a sample taken at the output amplifier. As mentioned previously, this action is instantaneous and, because overload of transmission facilities is undesirable regardless of cause, the circuit operates on signal level only and does not contain any sampling filters.

The combined d-c control quantities are amplified in a chopper-amplifier, rectified and applied to the variolossor.

Figure 8 shows the output for both sine wave and speech inputs. There is no gain increase action for either signal for input levels below threshold. In this range, the output follows in input, db for db, as in any fixed gain amplifier. At the threshold point, the speech output level jumps to 0 vu with, of course, the time delay shown in Figures 6 and 7. The output stays at this level for speech inputs that are more than 40 db above threshold.

Sine waves do not affect the gain increaser. For these the unit acts as a fixed-gain amplifier until the gain-decreasing point is reached. There is a 7 or 8 db difference between the two curves at full output. This difference is based upon a 3 db peak factor for sine waves and an assumed 10 db peak factor for sine waves and an assumed 10 db peak factor for speech as read on a vu meter. On this basis, both signal outputs would have the same peak value and all below the amplifier breakpoint.

Although inferred in the previous discussion, it is important to note that the AGAMP does not go to full gain during "no signal" intervals, but remains at nominal gain. When signals above threshold value are present it regulates ± 20 db from nominal gain.

Devices that go to full gain during idle conditions accent circuit noise by providing more amplification to the noise alone than when signal is present. Yet, the signal acting upon the ear provides a masking effect for noise that would encourage the opposite gain sequence.

THE CLIPPER-LIMITER

The block diagram for a typical clipper-limiter type amplifier is shown in Figure 9. The signal path is through the input transformer, level control, phase inverter and push-pull variable gain, driver and output stages. The signal is sampled at the output stage by a full-wave rectifier. Also applied to the rectifier is an adjustable d-c bias voltage. Only portions of the signal that exceed the bias allow the rectifier to conduct. The rectifier output is applied through a resistance-capacitance network to control the bias on a variable gain stage. The resistance-capacitance network provides the attack and recovery time constant for the unit. For the unit tested, the attack time constant was 12.5 milliseconds and the recovery time constant was 1.0 seconds.

Gain and input-output transfer characteristics for a clipper limiter are shown in Figure 10. It will be noted that for the most favorable choice of input levels, a 40 db input range is reduced to a 21 db output range. For the lower 15 db of the input range, as well as for the no signal condition, this unit has 67.5 db gain. At higher inputs the gain is reduced proportionally to a minimum gain of 50 db.

The unit tested has an advertised "flat" noise level output of -46 dbm at a 70 db gain setting. The particular unit tested had a measured -43 dbm "flat" noise or 30 dba (F1A) at 67.5 db gain.

THE COMPANDOR

The question has frequently been asked by telephone people who are familiar with the compandor, "Is it applicable to the mobile radio service?" As normally used in telephone installations, the compandor provides a compressor at the transmitting end of a circuit and expander at the receiving end. The assumption made in determining the advantage of the compandor is that a good signal enters the compressor and that any adverse noise condition will be encountered in the facility between the two elements.

The compressor accepts a 46 db input range which it compresses into a 23 db output range as indicated in Figure 11. Assuming that the highest level in the 23 db output range is applied to the circuit at the same level that would be used for the highest level uncompressed signal, the lowest level compressed signal would be 23 db higher than its uncompressed counterpart. This, naturally, results in a 23 db improvement in signal-to-noise ratio over a non-compandored line.

At the distant end of the circuit the compressed signal is applied to the expander portion of the compandor. This circuit expands the input in a two to one ratio to return the signal to its original relative location in the 46 db range. This allows each talker to maintain the level characteristic of his speech.

It is of interest to note in Figure 11 that one signal level designated as "focal point" is not changed when passing through the compressor and expander. All other signals are compressed or expanded in a 2 to 1 ratio db-wise relative to the number of db they are from the focal point.

A block diagram of the compandor is shown in Figure 12. The signal enters the compressor via the 600 ohm input transformer. It then passes through a variolossor and amplifier. At the amplifier output the signal is applied to the line from one winding of the output transformer. Another winding of this transformer feeds a bridge rectifier which in turn supplies d-c control current to the variolossor. As in the AGAMP, the variolossor determines the overall gain of the unit.

The expander operates in a similar manner although the signal passes through the elements in a different sequence.

In the mobile radio service intelligibility is more important than reproducing a voice in its relative position in the level range. This philosophy was tacitly presumed when use of the AGAMP and clipper-limiter were considered. To continue with this approach, it is apparent that use of the compressor portion of the compandor would result in performance very similar to the clipper-limiter -- namely, reduction of the 40 db input range to a 20 db output range.

CONCLUSIONS

In the preceding discussion, statistical data was presented to show that the input range for a level controller would be 30 db if the circuit loss between the microphone and controller was fixed and only level variations between individuals need be considered. If circuit loss variations were added to this, the range would be increased to 40 db.

At the output of the level controller, maximum levels were established for the telephone circuit and for the transmitter input. However, no allowable range of levels was mentioned. To determine this range in a rigorously sound engineering manner one would, no doubt, have to conduct statistical studies of articulation and intelligibility for a large number of talkers and listeners. However, some practical, though qualitative, conclusions can be made by observing these level controlling units in action.

In order to do this, an excerpt from a speech was played from a tape recorder into a variable attenuator. The attenuator was changed in 3 db increments from 0 to 39 to 0 db at approximately a three second per step rate. The output of the attenuator was fed in turn to the AGAMP, a fixed gain amplifier, the clipper-limiter, and the compressor section of the Compandor. The output of each unit was then recorded on a second tape recorder. Fixed attenuators were used as required to maintain the

recommended input level for each device and to keep the maximum output levels equal.

Although the conclusions here are those of the writer, the tape will be played so the listening audience may make its own analysis of the level control problem.

1. It is obvious that a 40 db range is intolerable and that some sort of control is required.
2. A 30 db range appears to be about the largest that can be handled without level correction. With this range, the highest level could border on uncomfortable listening and reception of the lower level could be lost due to ambient conditions.
3. The devices that provide 2 to 1 correction, the clipper-limiter and the compressor section of the Compressor, approach a limit for the 40 db range but would provide a usable output. They appear to have considerable merit for the 30 db input range.
4. With the Agamp, Vogad, it is virtually impossible to distinguish one portion of the 40 db input range

from another. This device offers nearly perfect control of speech levels.

5. In using or selecting the level controller thought must be given to the operational characteristics of each unit in respect to noise and tones that may be encountered in a particular application.

To summarize these characteristics, the Agamp rests at nominal gain during idle circuit conditions and will not increase gain on tones or random noise. It will decrease gain on any signal above nominal. With this device, it is usually preferable to feed signaling tones into the circuit after the Agamp. Advantages of this unit are that it provides essentially constant speech output, does not accent idle circuit line noise, and does not increase gain or noise.

The other units will react to signal, noise, or tones. While in some applications this is a disadvantage, it appears that these units could be used to advantage at base receivers where both voice and tone may be included in the receiver output and where the level variation is in the order of 30 db.

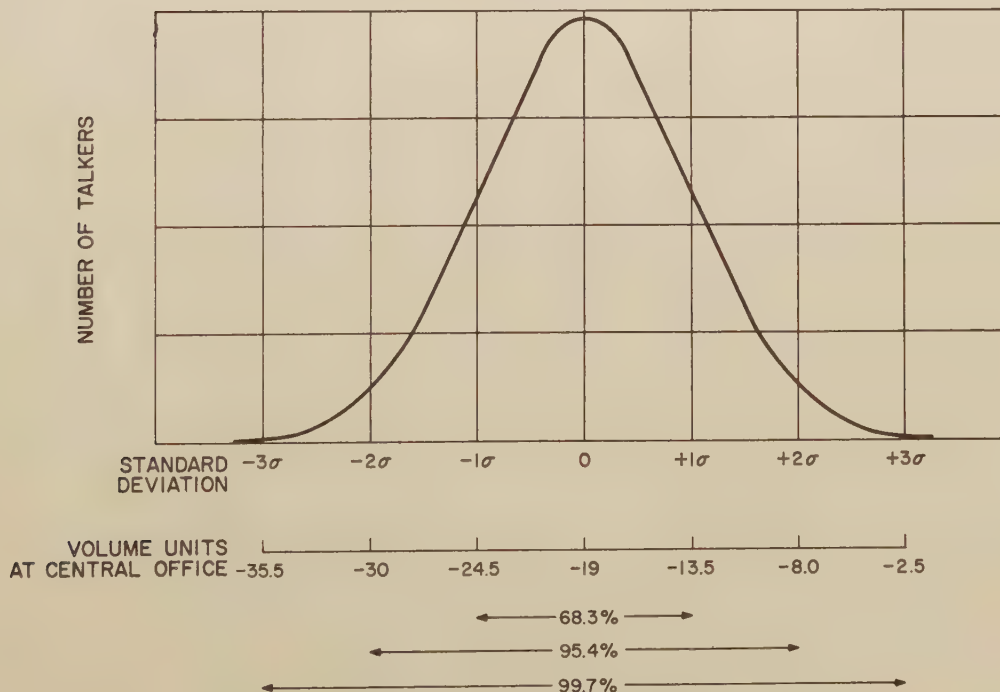


Fig. 1 - Normal distribution curve showing speech levels at the central office.

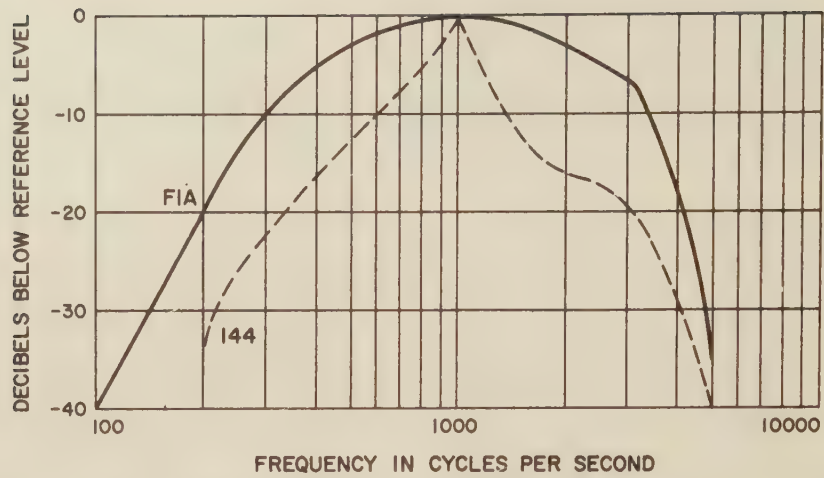


Fig. 2 - Weighting curves commonly used in noise measurements.

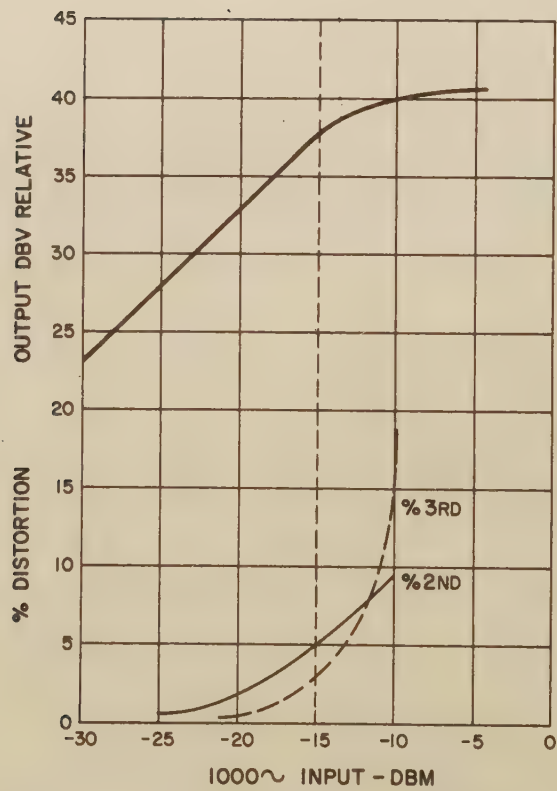


Fig. 3 - Typical transmitter input characteristics.

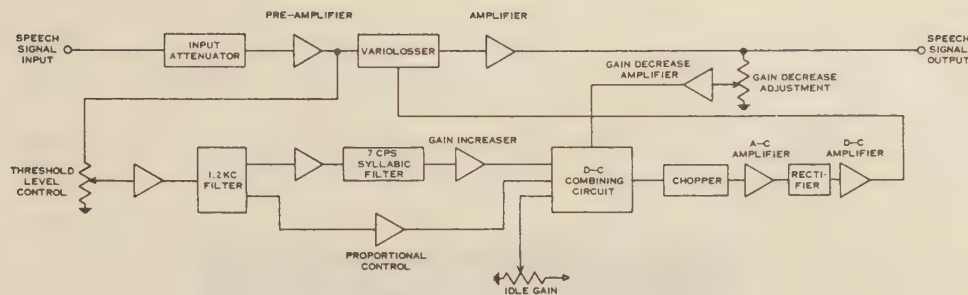


Fig. 4 - Block diagram of AGAMP showing functional division of circuit and all adjustments.

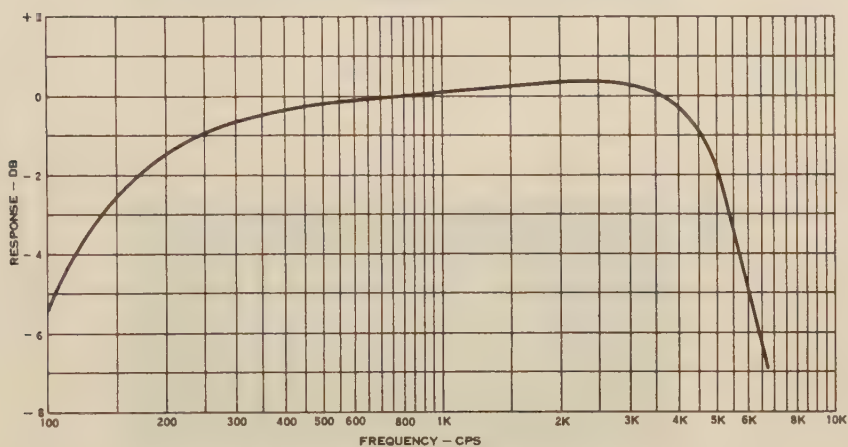


Fig. 5 - Frequency response of AGAMP signal path.

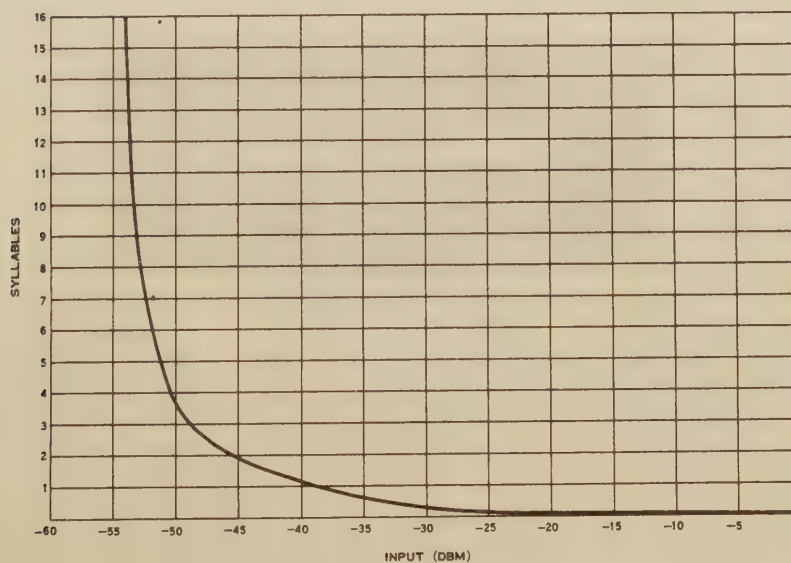


Fig. 6 - Attack time characteristic of AGAMP for the entire input level range.

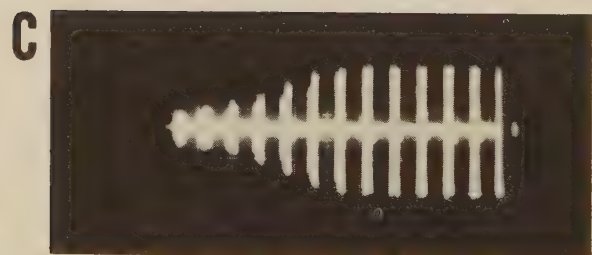
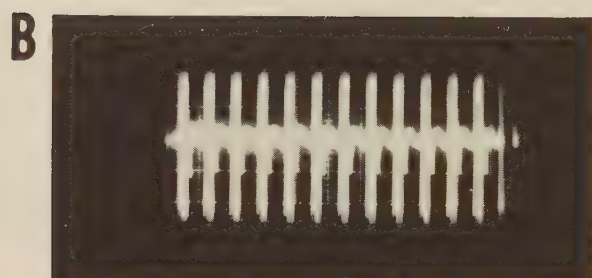
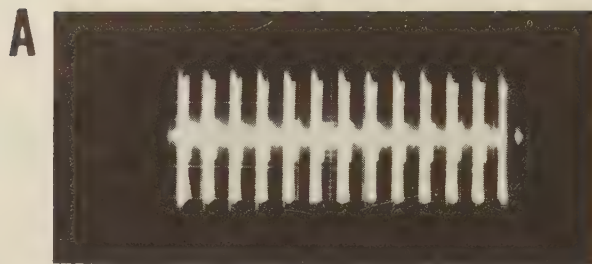


Fig. 7 - AGAMP response time for (A) -14 DBM input, (B) -36 DBM input, (C) -53.5 DBM input. A 1000 cps signal interrupted at a 7 cps rate was used to simulate speech.

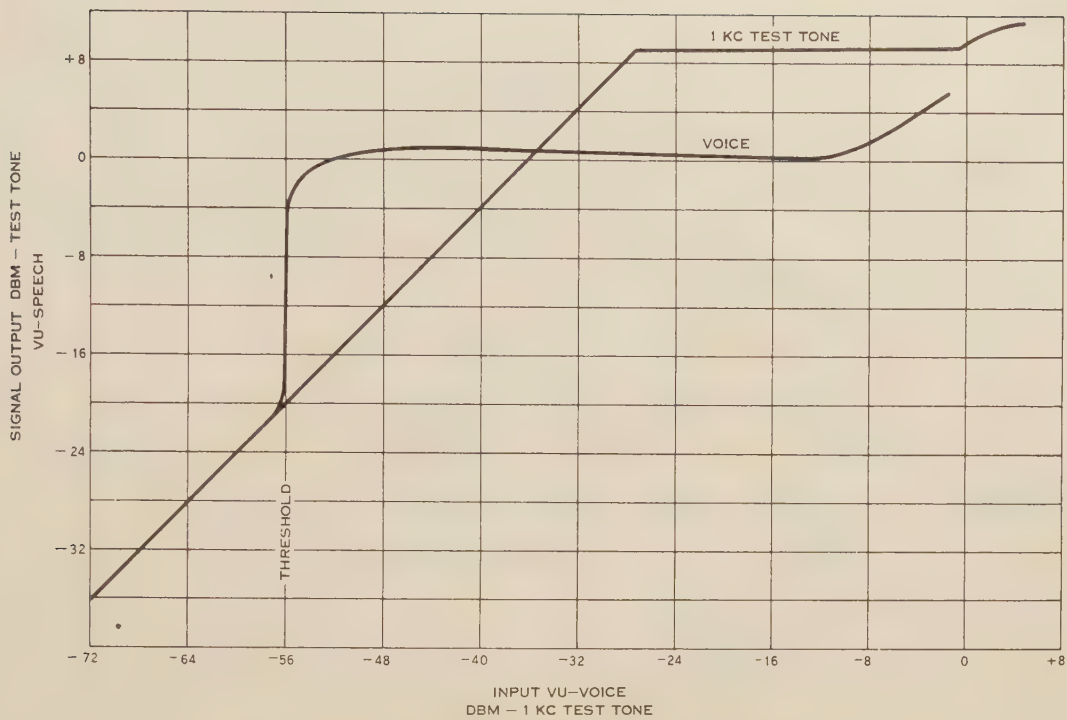


Fig. 8 - Gain characteristics of the AGAMP for voice and tone inputs.

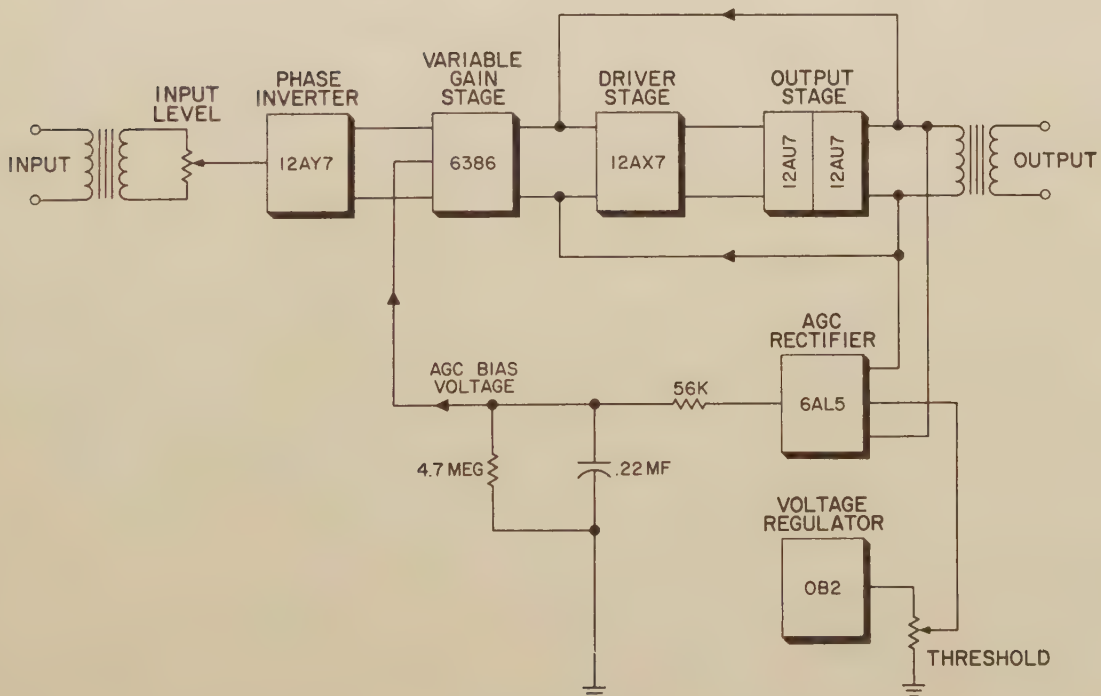


Fig. 9 - Block diagram of clipper-limiter type amplifier.

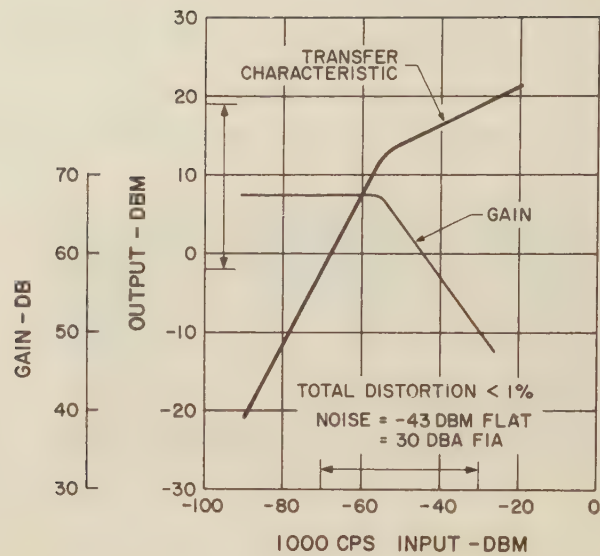


Fig. 10 - Gain and transfer characteristics of the clipper-limiter.

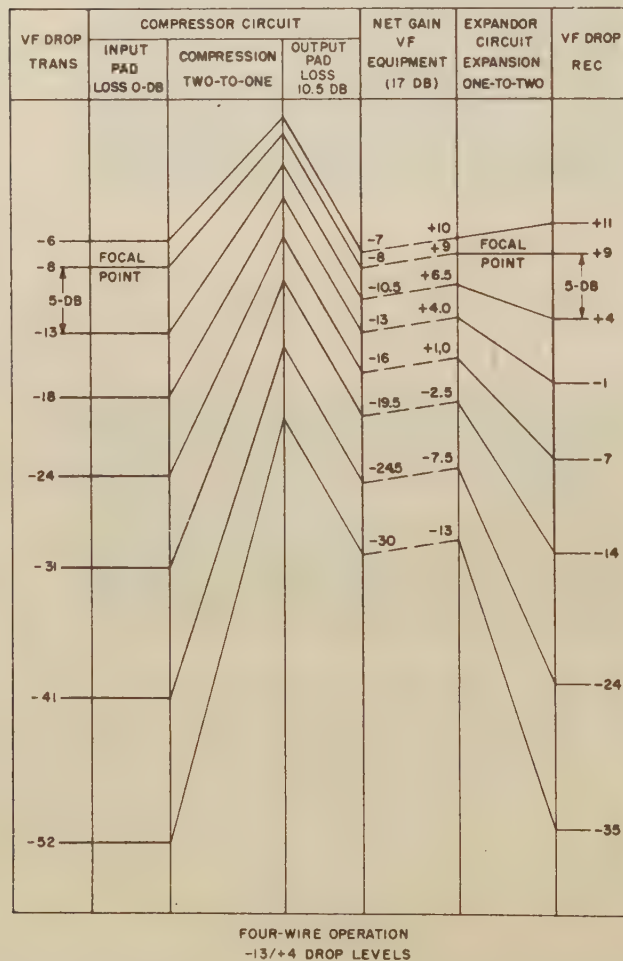


Fig. 11 - Compador transfer characteristics.

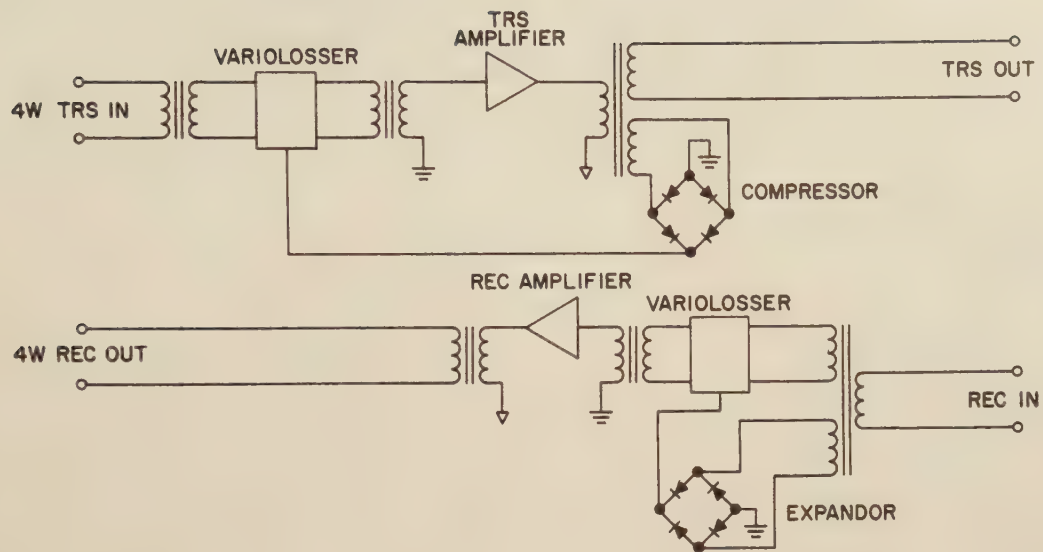


Fig. 12 - Block diagram of compander.

MEASUREMENT OF DEVIATION AND FREQUENCY IN F. M. TWO-WAY RADIO SYSTEMS

M. COOPER

INTRODUCTION

A plea for proper setting of deviation and frequency before a group having the stature of the PGVC would appear to be as necessary as a strong pitch for motherhood before the local PTA. Certainly everyone believes in it. Many two-way systems users have not, however, realized the full importance that these parameters have attained since the tight tolerances of the split channel have been imposed upon us.

I will attempt, in this paper, to discuss some of the theoretical considerations regarding frequency modulation deviation, and to briefly peruse a few of the more practical aspects of deviation and frequency measurement. I promise to use the expression "Bessel Function" only once, just to give it official cognizance of this conference, and to leave any mathematical derivation to the more ambitious readers.

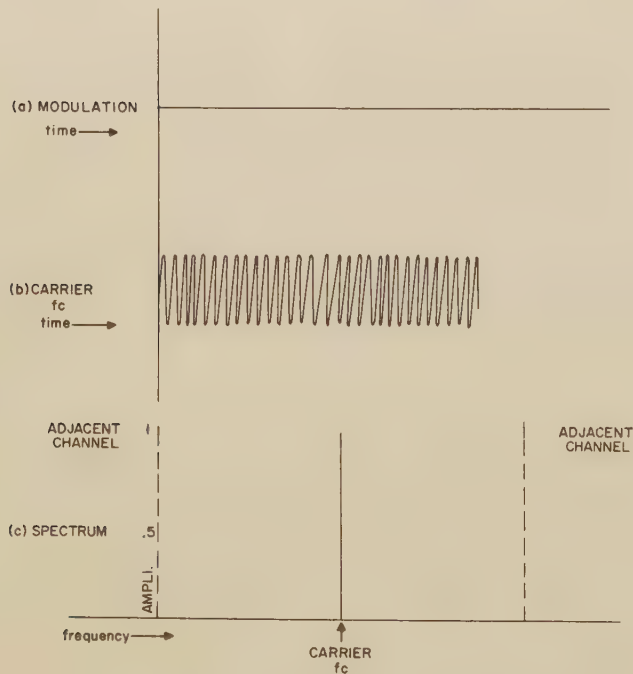


Fig. 1 - Unmodulated carrier.

SOME THEORETICAL CONSIDERATIONS REGARDING F. M. AND P. M.

The simplest way to describe the various signals associated with modulation is in the use of the time and frequency graphs as shown in Fig. 1. Fig. 1(a) and 1(b) represent plots of the amplitude of the modulating signal and carrier as a function of time. Fig. 1(c) is a plot of the frequency spectrum resulting from the combination of carrier and modulation.

An amplitude modulated signal is displayed in Fig. 2. Note that the degree of modulation is very clearly indicated by the time plot of the carrier (which could easily be an oscilloscopic trace) and that the spectrum, assuming distortionless modulation, consists of only three distinct frequencies, the carrier, and the two-side bands spaced at an interval equal to the

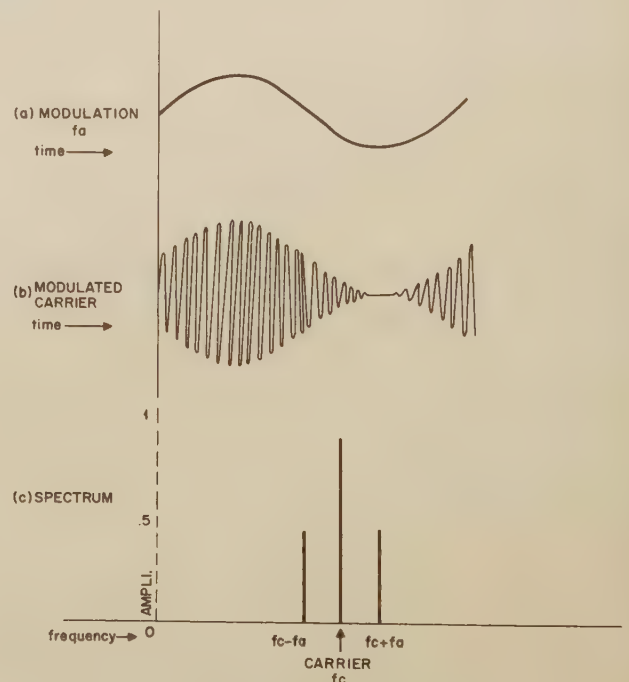


Fig. 2 - Amplitude modulation.

modulating frequency. The power in the carrier is a constant and a pair of sidebands is added for each modulating frequency. For linear modulation, the energy in the sidebands may not exceed half the carrier power. As long as the carrier is not over-modulated, the sidebands resulting from multitone transmission are all independent and have no effect upon each other.

The picture is quite different for phase or a frequency modulated signals as shown in Fig. 3. We note here that, even though the modulation is distortion-free, a large number of sidebands appear, spaced at intervals equal to the modulating frequency. Unlike the A.M. case, the total power in the sidebands and carrier is equal to that of the unmodulated carrier and the carrier may be larger or smaller than the sidebands. In fact, the carrier actually disappears under some circumstances. Addition of modulating frequencies causes a redistribution of transmitter energy, but the F.M. or P.M. sidebands are all inter-related and sidebands occur at intervals equal to the individual modulating frequencies as well as various combinations of these frequencies.

A few words on the difference between Frequency Modulation and Phase Modulation are in order at this point. As indicated in Fig. 3, the spectra of the two systems are identical for the same modulating frequency and degree of modulation.

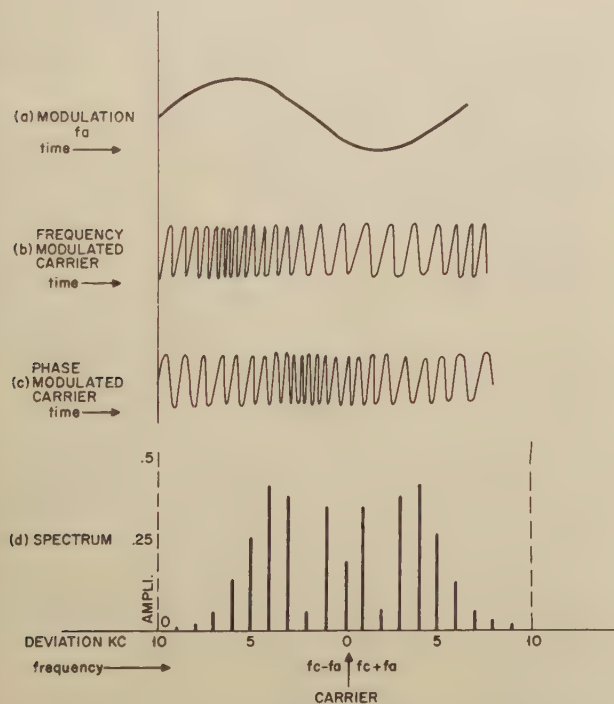


Fig. 3 - Frequency modulation & phase modulation.

The 90° phase difference shown between Fig. 3(b) and 3(c) is not important and does not affect the spectra or recovered signal. It is only when the spectra of different modulating frequencies is observed that the difference becomes obvious. Fig. 4 shows the spectra of an F.M.

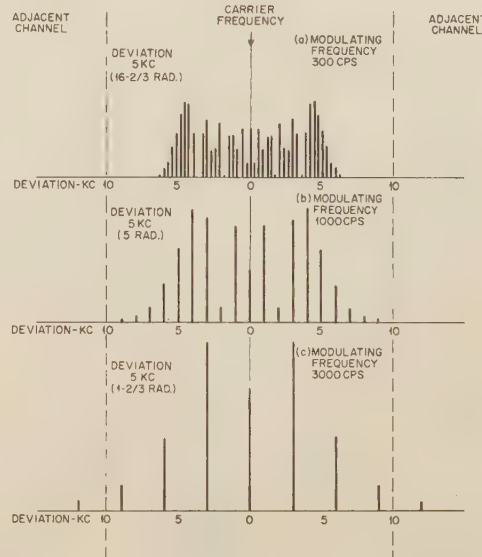


Fig. 4 - Frequency modulation spectra with variable modulation frequency.

signal having 5 Kc deviation with modulating frequencies of 300 cps, 1000 cps and 3000 cps. Note that the envelope of the spectra is practically independent of the modulating frequency. On the other hand, phase modulation spectra for the same frequencies and a constant phase shift of 5 radians indicates, in Fig. 5, that the width of the phase modulated spectrum is a direct function of the modulating frequency.

It is clear now that the two forms of modulation are identical except that for F.M. having a fixed deviation, the phase angle of modulation decreases directly with increasing frequency and for P.M. having a fixed phase angle, the deviation increases directly with frequency.

Regardless of the type of modulating and detecting circuitry, an F.M. system can be converted to P.M. or vice versa by appropriately adjusting the frequency response prior to modulation and after detection. To convert a P.M. modulator to F.M. we need only de-emphasize the high frequencies relative to the low frequencies at 6 db per octave. On the other hand, an F.M. modulator can produce P.M. with addition of pre-emphasis. De-emphasis applied to the modulation described by Fig. 5 will convert it to the spectra of Fig. 4.

Because of certain characteristics of voice and of the recovered noise in pure F.M. transmission, most so-called F.M. systems in use today, including broadcast F.M. as well as F.M. mobile radio, are to a large extent actually P.M. systems.

Since the channels allotted to mobile use are so closely spaced, some means must be provided to limit the modulation in such a way as to prevent splatter into adjacent channels and thus to prevent interference between channels. It is also desirable to keep as much of the transmitted power as possible within the receiver bandpass to maximize receiver performance. Even though phase is the variable of modulation in our system, it is evident from Figs. 4 and 5 that limiting of phase alone, which is equivalent to limiting the modulation amplitude in P.M., will be inadequate to prevent splatter. It is the rate of change of phase, or deviation which must be limited.

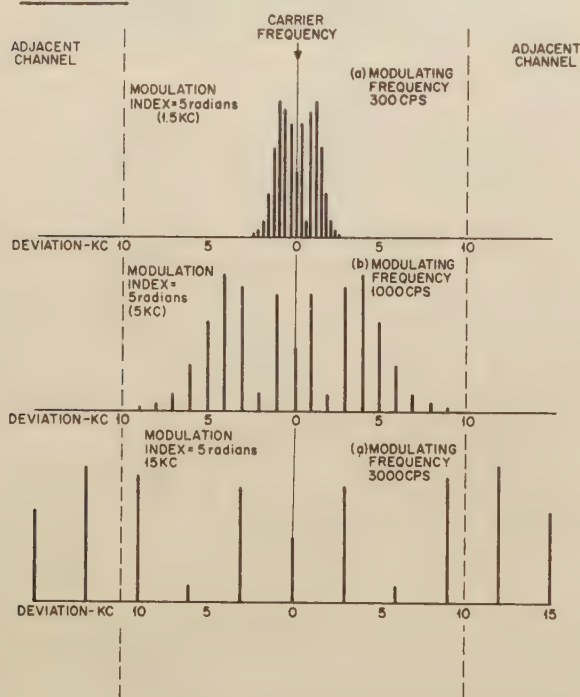


Fig. 5 - Phase modulation spectra with variable modulating frequency.

To illustrate this, consider a split band system with 3 Kc audio bandpass. It has been determined that, to prevent excessive spreading of the spectrum the peak phase shift at 3000 CPS should not be greater than one and two-thirds radians which is equivalent to 5 Kc deviation. If the modulation is limited to 1.67 radians for all audio frequencies, splatter will no longer be a problem but only a very small portion of the spectrum will be used at the low audio frequencies (i.e. 500 cps deviation at 300 cps modulation). Now, if our objective is to transmit all audio

frequencies with equal maximum fidelity, such a system would be necessary. For voice transmission, however, we would be penalizing the spectrum of maximum voice energy from 300 to 800 cps in order to get faithful transmission of seldom used high frequencies. The characteristics of the human voice are such that high frequency high amplitude peaks can be removed without degrading intelligibility and, in some cases, actually improving it. It is for this reason that two-way radio systems use a form of instantaneous deviation limiting. With this form of limiting, low level signals of all frequencies use true phase modulation. As the level is increased, high frequencies are clipped first and as level increases further, clipping may extend to lower frequencies.

DEVIATION MEASUREMENT

Since a maximum deviation has been determined as a prime system criterion, measurement of this factor becomes important. The fundamental requirement for this measurement is a broad bandwidth receiver having a wide, linear, discriminator (a ratio detector or phase detector could equally well be used provided they can be made to recover the full deviation range faithfully). The receiver bandwidth must be adequate to include all significant sidebands of the signal to be measured. Attenuation of some of the sidebands will distort the recovered audio and thus affect the accuracy of the result. The discriminator must be compatible with the receiver bandwidth and linear to the degree of measurement accuracy required.

It is now necessary to add some form of indicating device to display the discriminator output and to calibrate the entire instrument for deviation readings. The most direct, and generally the most accurate, indicator is a cathode ray oscilloscope having a low distortion vertical amplifier. A meter may be calibrated for deviation measurements provided that certain precautions are taken. The most important transmitter deviation measurement is made when the deviation limiting circuit is fully operative. Under this condition, the recovered signal is quite distorted as seen in Fig. 6 and the only significant measurement which can be made is a peak to peak or peak to average voltage reading. The oscilloscope measurement is easily made by counting squares on the reticule. A true peak measuring meter may be used provided that the scale is calibrated to the discriminator used. Even with an accurate peak reading meter, some error may be introduced if the recovered signal is unsymmetrical as is the case with certain forms of distortion.

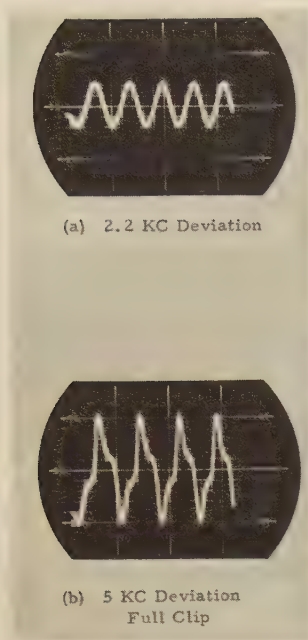


Fig. 6 - Deviation measurement by oscilloscope.

Many signal generators and monitoring equipments incorporate a deviation meter which is deflected by the average or r.m.s. value of the detected signal but which has a scale calibrated in peak deviation frequency. These meters will read correctly only for a distortionless sine wave modulation and will be in error for any other waveform. A low distortion signal may be used with such a meter to calibrate an oscilloscope reticule but the meter must never be used for reading deviation of a limited signal. Provision is often made for checking the meter calibration by applying a standard audio signal directly into the meter circuit.

The most precise calibration method for any indicator involves use of the carrier disappearance phenomenon which was mentioned previously. When the peak phase shift or deviation ratio (ratio of peak deviation to modulating frequency) equals 2.40, 5.52, 8.65, etc., the amplitude of the carrier becomes zero and all the transmitted energy is in the sidebands. Thus, if the disappearance of the carrier is measured for a given modulating frequency, the indicator can be calibrated using one of the ratios above. Fig. 7 shows block diagrams of two test set-up for this type of calibration and a typical spectrum. The method illustrated in Fig. 7(a) involves use of a heterodyne frequency meter to mix the modulated calibrating signal with an unmodulated carrier fixed several hundred cycles from the modulated signal. The modulation is turned off, the beat note detected aurally and the modulation turned on again and

varied in level until the beat note disappears. Considerable difficulty may be encountered in aurally separating the beatnote from the modulation sidebands which occur when the modulation is turned up. The use of a spectrum analyser as in 7(b) produces the same results without the confusion of the sideband beatnotes. The resultant spectrum is shown in Fig. 7(c).

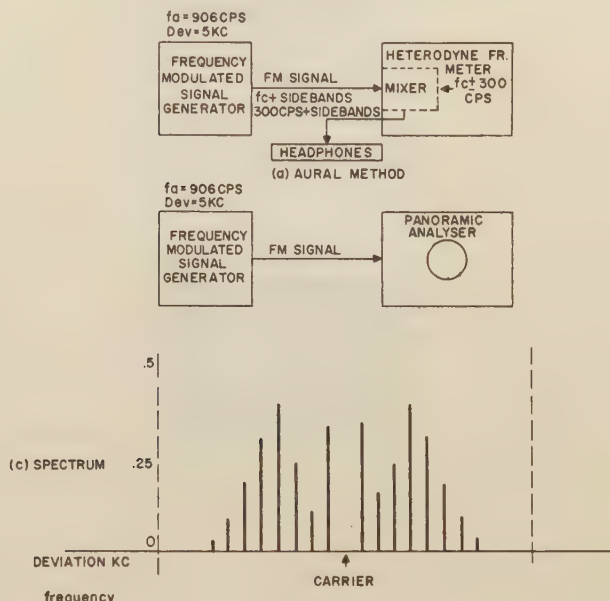
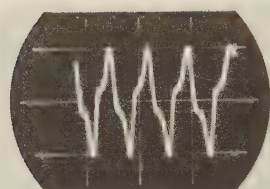


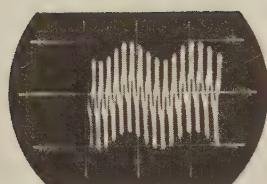
Fig. 7 - Carrier disappearance.

One pitfall in this technique is worth mentioning at this time. The spectrum produced by a single frequency signal phase modulating a carrier contains the same frequency components as the carrier modulated by a distorted signal. Only the relative amplitudes of the sidebands change. Thus, a distorted audio modulated carrier will appear similar in spectrum to the pure sine wave case and will display the carrier disappearance phenomenon. The nulls will not occur at the predicted deviations and results will be erroneous to the degree that the signal is distorted. Care must be taken to insure that any signal used in this calibration method is not in clip and is reasonably distortion-free.

Actual measurement of deviation once a calibrated indicator is available becomes a simple matter. It is only necessary to modulate the carrier with a 1 Kc signal 20 db greater than that required for two-thirds system modulation and to set the deviation control of the transmitter to provide rated peak deviation. If the system uses a form of tone squelch, the tone must be included as shown in Fig. 8(b). The oscilloscope faces in Fig. 8 have been calibrated at 1 kc per division and the transmitters properly set at 5 kc deviation.



(a) 1 KC Modulation



(b) 1 KC Deviation With
Tone Squelch

Fig. 8 - Proper deviation setting.

FREQUENCY MEASUREMENT

The short space to be devoted to frequency measurement in paper is not intended to minimize the importance of this factor. Mis-setting of frequency in split channel systems can reduce performance drastically both in area coverage and in intelligibility.

Setting of frequency requires only a known accurate standard and a means for comparison of this standard with the oscillator under test. In the case of receiver setting, the discriminator may be used as a zero indicator. Most secondary standards include a form of indicator consisting of a mixer, low pass filter, detector, and meter.

Fig. 9 illustrates a tone spectrum of a split channel transmitter superimposed upon an on fre-

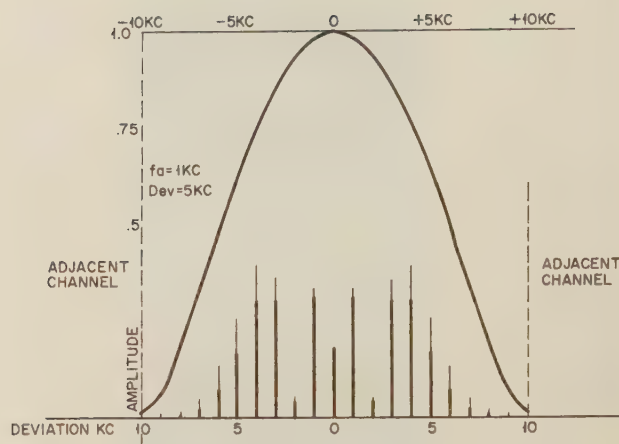


Fig. 9 - Split channel spectrum and receiver bandpass.

quency receiver bandpass characteristic. The sidebands which are attenuated when the bandpass is moved to one side or the other are effectively lost transmitter power as far as any given receiver is concerned. In addition, as more sidebands are lost, noise appears in the receiver output to further degrade performance. The result of these effects is a reduction in range and generally poor communications. Even where signals are strong, the off-frequency signal is highly distorted and has reduced intelligibility.

Frequencies should thus be checked at reasonable intervals, at least every 6 months, to eliminate this source of degradation.

To meet FCC requirements, the secondary standard used as a station monitor must be checked against a primary standard such as Radio Station WWV every 6 months. Suitable receivers for this purpose are generally included with station monitor equipment.

CONCLUSION

The time spent in accurately setting the deviation and frequency in an F.M. two-way radio system will be well rewarded by the improvement in system performance. The appreciation of your neighbor channels for keeping within your home grounds comes as an extra bonus.

SINAD SYSTEM DESIGN

R. A. Farmer

General Electric Company
Communication Products Department
Lynchburg, Virginia

Summary

This paper deals with performance parameters used in designing a communication system, black boxes and all, rather than with the circuit parameters needed to design the individual equipments which make up the total system. There is a common language for use in the Land Mobile Services which should, but does not yet, have the stature of CCIF and CCITT specifications used by system designers in the field of point-to-point communications. The Electronic Industries Association (EIA) specifications for Land Mobile equipment are examined and their applicability to system design work is discussed.

Introduction

An "engineered" mobile system requires proper evaluation of equipment performance specifications, propagation characteristics, the influence of noise, and due consideration of control and other factors as well. While many methods are successfully used in system design, each seems to use different terms and measurements, different quantities, and perhaps a special figure of merit favored by the individual designer. As a result, a basis for comparison seldom prevails in spite of the system designers' common goal to determine and specify the equipment and system objectives. A review of some industry standards shows that this situation can be improved.

Use of EIA Definitions

Useable Sensitivity

The design of a communication system always includes manipulation of power levels to achieve the desired signal-to-noise performance. This quickly leads to a need to know the receiver sensitivity. The EIA specification for "Useable Sensitivity" replaces the 20 DB Noise Quieting sensitivity by bringing a more sophisticated meaning to this important receiver specification. A comparison of the measuring techniques shows the superiority of Useable Sensitivity.

Noise quieting is measured by first taking a reference reading of unquieted receiver noise. An RF signal is then applied so as to obtain 20 DB of quieting. Good sensitivity figures tell a great deal about receiver design between the antenna and the discriminator, but are primarily a measure of AM limiting. Furthermore, the measurement tells very little about

stages after the discriminator since audio distortion has such a small affect on the noise reference reading.

From a system standpoint, a measurement is needed which includes the entire receiver, and which will show the amount of audio distortion. In order to do this, the EIA method of measurement calls for modulation on the RF carrier so that a test tone is applied to the receiver audio stages. Figure 1 shows the audio output spectrum which is measured to determine "Useable Sensitivity". A wide-band meter is used to get a reference reading produced by the test tone (S) and its harmonic distortion products (D). Everything else which contributes to this meter reading is considered to be noise (N). When a slot filter removes the 1 KC test tone from the meter, the noise and distortion products are measured alone. The ratio of these two meter readings is expressed in DB, and is frequently called the Sinad ratio. Useable receiver sensitivity is the number of RF microvolts needed to obtain a 12 DB Sinad ratio.

Figure 2 compares two low-band, narrow-band receivers which have the same noise quieting sensitivity and which might be expected to perform equally well. However, as the RF input is increased so that noise quieting begins, the Sinad curve becomes limited by harmonic distortion produced in the audio stages. Receiver B has far more distortion than receiver A; in fact, its maximum Sinad ratio is 10 DB less than the maximum for receiver A. Since the receivers were identical up to the discriminator, both have the same noise quieting characteristic. Note that the limiter continues to produce noise quieting beyond the point where audio distortion limits the Sinad ratio of either receiver.

The on-channel performance of two receivers can be compared by Sinad measurements; they cannot be compared by quieting sensitivity since this fails to include audio distortion.

Receiver Selectivity

A new EIA specification for Land Mobile Communication Systems includes measuring techniques that cover other aspects of system performance, particularly measurements between microphone input and a dummy loudspeaker. An RF attenuator connects the transmitter output to the receiver input so that closed-circuit condi-

tions are maintained. Measurements made in this manner include noise and distortion products of both the transmitter and its companion receiver. External interference which would be introduced between transmitting and receiving antennas is excluded since the intent is to measure all features of the equipment itself. These measurements also use the same 12 DB Sinad objective as does receiver sensitivity.

One of the system standards includes criteria for the performance of one system in the presence of others on the same, or on nearby channels. There are many different ways to measure the noisewidth and skirt selectivity of a receiver. One old-fashioned way is to measure noise quieting with one, unmodulated signal applied. This method actually measures the overload characteristic of a receiver and, since overload occurs ahead of the selective circuits, the measurement conveys very little information about the performance when two signals are present. For selectivity to indicate the interference rejection capability of a receiver, it must be measured with two signals present. The EIA method for selectivity measurement uses an on-channel signal to produce a 12 DB Sinad ratio. An adjacent-channel signal is then applied simultaneously with the desired signal, and is adjusted to reduce the Sinad ratio to 6 DB. Such a method, by using two signals, both modulated, comes much closer to the "real-life" situation than any other selectivity measurement.

How Good is a Sinad

The measuring techniques used for equipment and for closed-circuit systems make much use of a 12 DB Sinad ratio. To get some feel for the qualitative meaning of Sinad, a number-recognition curve is useful. Figure 3 was made with typical Land Mobile equipment. It shows how a system would perform because the modulating power varies, and because the deviation-limiting circuit has come into play. For an average talker, the Sinad ratio will vary, but will not exceed the peak value shown.

A sentence-recognition curve would lie above the number curve since a message is usually understood in spite of missing words. On the other hand, random word recognition is more difficult, and its curve would fall below the number curve. Perfect recognition of random words cannot be obtained even in a face-to-face conversation.

Note in the number-recognition curve that a 12 DB Sinad results in 95% recognition. Should some form of interference reduce this to 6 DB Sinad, the recognition drops to about 50%. Such curves give a general indication of the dynamic relation between Sinad and the quality of a circuit.

System Sinad

For lack of a universal or measurable figure of merit which can be used to appraise the performance of mobile systems, these are designed by fitting the equipment performance specifications to the anticipated transmission conditions, basing this design on test-tone measurements. A simple case is the Mobile Relay Station used to extend mobile-to-mobile coverage. Since this station uses a transmitter and receiver in the same cabinet operating full-duplex, it must reject interference of its own making. This interference is in two forms, as shown in Figure 4. Every transmitter has in its RF output spectrum some noise which is significant several percent on both sides of the carrier frequency. This noise is about 75 DB down in the alternate channels and is uniform in the acceptance band of a receiver. Its presence reduces the RF signal-to-noise ratio. For a frequency spacing of 300 KC, this noise must be attenuated by about 62 DB to prevent more than a 6 DB degradation in a 12 DB Sinad circuit. When the frequency separation is increased, transmitter noise becomes less significant and the carrier itself can overload the receiver, causing a loss in its gain. In the Receiver Desensitization curve, note how this overload becomes the predominating influence for separations in excess of one megacycle. The attenuation necessary to overcome these two forms of interference can be obtained by some combination of antenna spacing or RF cavities, using the other curves shown.

In performing actual measurements of Sinad with interference present, it is easier to measure a 6 DB reduction than any smaller amount, hence the frequent reference to 6 DB degradation of a 12 DB Sinad ratio. This standard for measurement does not imply that a system should be designed on the same basis. The complete design must include allowances for all forms of interference; because of its widespread use in the EIA Standards, a 12 DB Sinad circuit makes a satisfactory starting point.

Site Noise

Site noise for a mobile unit includes both the ignition noise and other man-made noise from its immediate environment. Ignition noise tends to be comparatively constant. Even in the best mobile installation there is an irreducible minimum of ignition noise which usually exceeds the set-noise. There is some hope that the automotive engineers may work towards reducing this ignition noise, but there is no hope at all for a reduction of man-made "street" noise. Therefore, some margin must be engineered into a 12 DB Sinad system to offset this "street" noise. Figure 5 shows some typical site noise factors for different locations and frequencies. At the

receiver input, the desired signal would have to have the power level shown in order to give a 22 DB Sinad ratio in the presence of the existing noise. To fully appreciate the magnitude of this noise problem, the better low-band receiver shown in Figure 2 would require -14.5 DBW for a 22 DB closed-circuit Sinad ratio. When downtown, a 45 DB margin is required for the same performance.

The difference between metropolitan and rural noise also points out that system design depends somewhat on whether the mobile units will be located chiefly in the country, such as in the Forestry Conservation Service, or if they are taxis exposed to "downtown" noises.

Sometimes there is a choice of base station sites. Where this is the case, it may be well to make a noise survey. The recording of limiter current in Figure 6 shows the results of such a survey. It was taken for a five minute interval with a hi-band narrow-band receiver connected to a coaxial antenna 300 feet above street level. One microvolt at the receiver input produces a full scale deflection. Another recording was made with the antenna at a 60 foot elevation and the charts were analyzed to form the table showing persistancy of the noise. As can be seen from this table, noise peaks of one microvolt were present for 10% of the time when the antenna was 300 feet high. Since this level of noise prevails for 10% of the time, the system performance is determined by external factors more than by front-end noise of the receiver itself. In both cases, the antenna was downtown, and therefore surrounded by noise. If the primary coverage area is also downtown, there would be little advantage in using a gain antenna to pick mobiles out of the noise source. If the desired coverage area includes the suburbs, there would be two advantages in moving the base antenna site away from the noise center. First, it wouldn't get noise from all directions and, second, the benefit of a gain antenna would be realized in almost all directions.

Propagation and Terrain Variations

An area-type of system can be energized by plotting a 12 DB Sinad contour, using conventional calculations along many radials from the base station. At any fixed point on this contour there will be time-variations in the calculated path loss. These variations follow the Rayleigh distribution shown in Figure 7. If the medium path loss could be held constant, a point-by-point exploration of the contour would show that the path loss is also a function of position. This variation is shown in the empirical "Terrain Factor" curves. The variation comes from unanticipated diffraction and absorption losses due to trees and buildings, as well as from other affects which cannot be individually accounted for in the original calculations. In the curve for low-band, note that a 14 DB margin is necessary to insure that 99% of the locations will receive median

power. The situation is worse for 450 MC; however, this is partially compensated by the smaller amount of noise shown in Figure 6 for this frequency.

Conclusion

Methods of measurement have been examined for their application to equipment specifications and to system design. An important point is the use of a test-tone to adequately measure the entire receiver from RF input to audio output. The EIA method of closed-circuit measurement gives the system performance of the associated transmitter and receiver. It also can be used to show the true selectivity of a receiver.

Factors such as man-made noise and terrain variations, external to the equipment but requiring design attention, have been reviewed. While no single formula for system design is likely, the Sinad standards can be used as the basic building block upon which to design mobile systems.

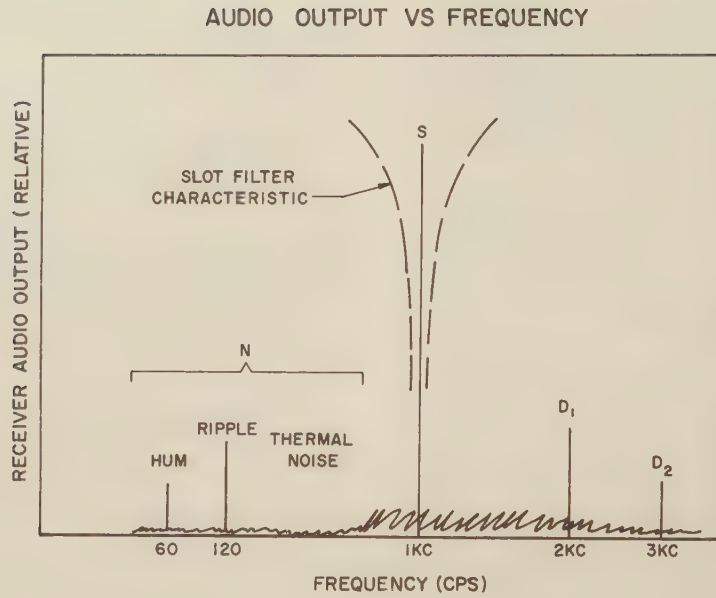


Fig. 1.

SINAD VS R.F. INPUT

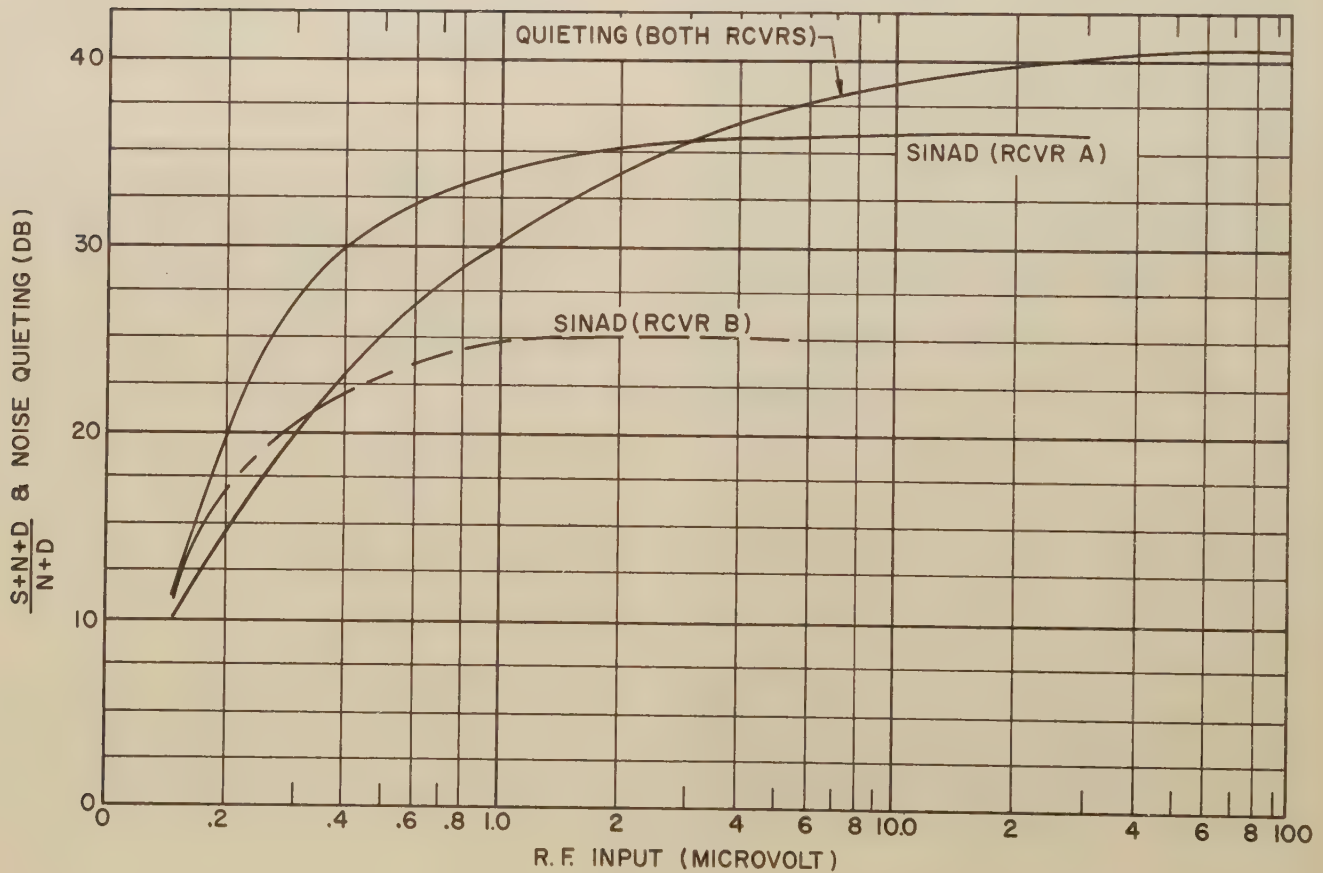


Fig. 2.

NUMBER RECOGNITION VS PEAK SINAD RATIO

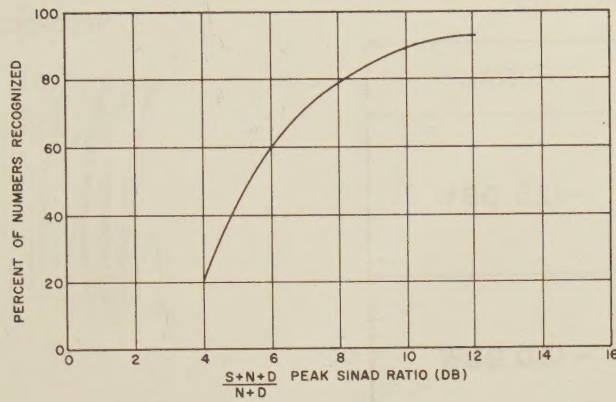


Fig. 3.

DUPLEX OPERATION (150 MC)

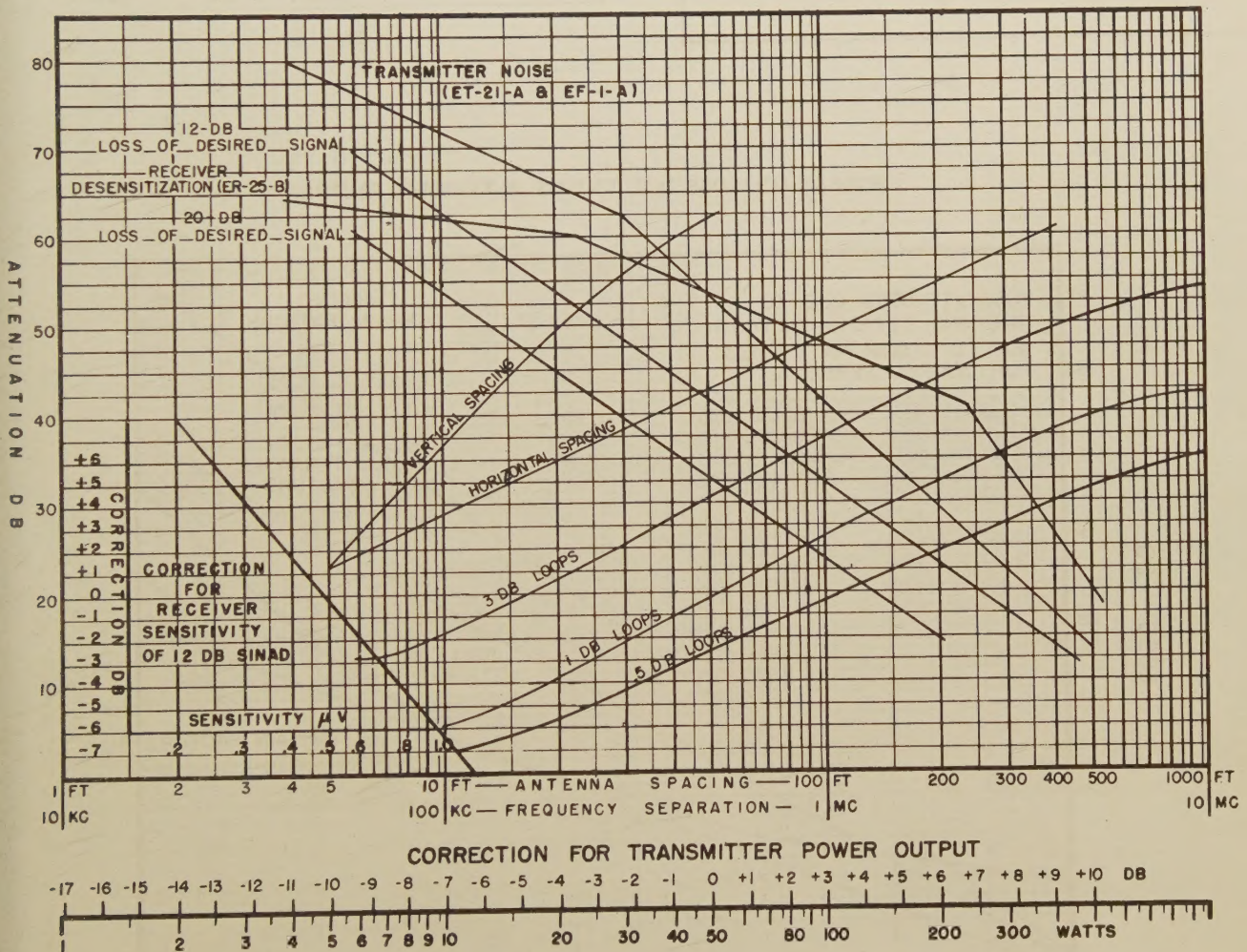


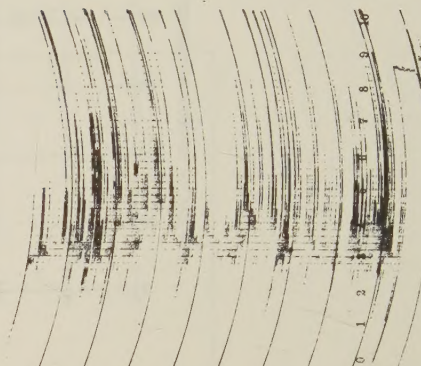
Fig. 4.

SITE NOISE FACTORS

TYPE FREQ.	METROPOLITAN	RURAL
50 MC	-100 DBW	-125 DBW
150 MC	-110 DBW	-130 DBW
450 MC	-120 DBW	-135 DBW

Fig. 5.

RECORDED SITE NOISE



INPUT MICROVOLTS	% OF TIME INPUT EXCEEDED			ANTENNA HT.
	10%	50%	90%	
1	0.45	0.2	300 FT.	
0.75	0.35	0.2	60 FT.	

Fig. 6.

PROBABILITY LOSS DUE TO TIME & TERRAIN FACTORS

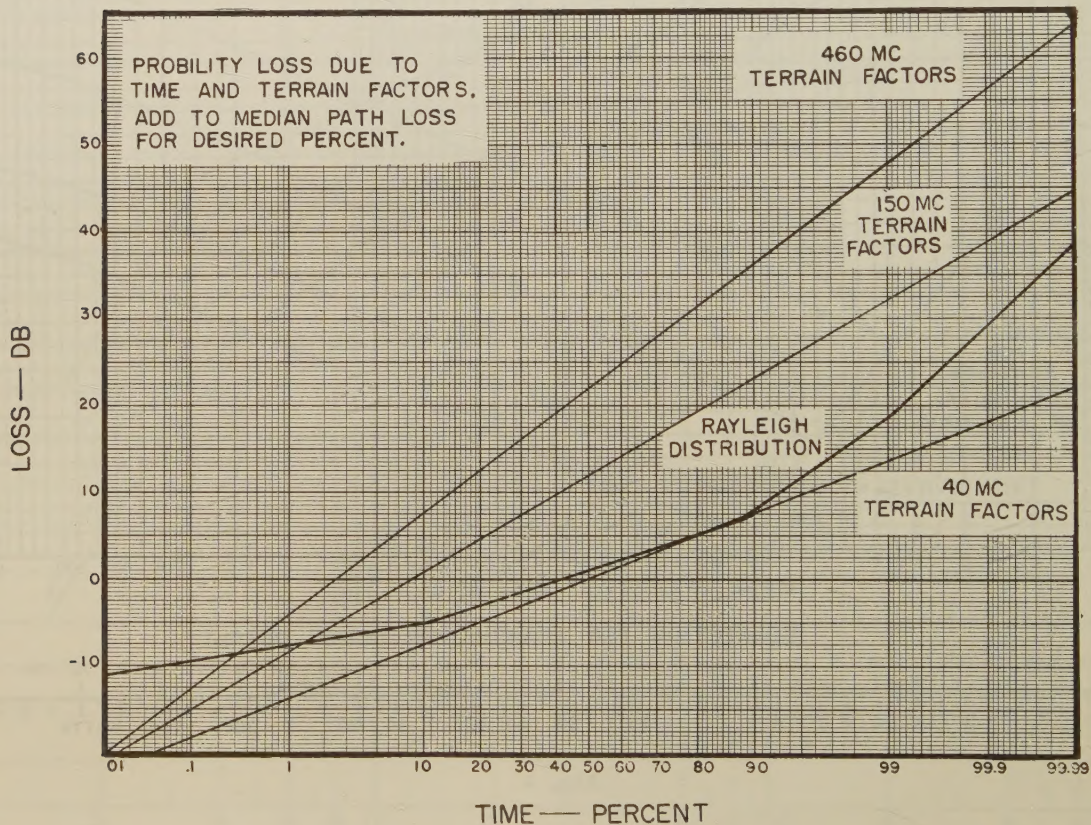


Fig. 7.

